FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT

PROJECT TITLE: AN ASSESSMENT OF STOCKS OF THE PEARL OYSTER *PINCTADA MAXIMA*

PROJECT NO. 88/93

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SUMMARY

A three year study of the pearl oyster *Pinctada maxima* in Western Australia was carried out to provide basic biological data and to develop an understanding of the status of the stock. Aspects examined were:

1. The location of stocks within Western Australia, both geographically and by depth.

2. The population characteristics of the stocks, with emphasis on growth rates and fishing mortality rates.

3. The reproductive status, which included an examination of the reproductive cycle over a large part of the range of *P. maxima* in Western Australia and an assessment of the genetic status of pearl oyster stocks across northern Australia.

4. The measurement of recruitment, using both spat collectors and surveys of the abundance of naturally occuring spat.

5. The further development of the fishery logbook to provide more detailed data on the operations of the fishing fleet and an understanding of fishing fleet behaviour and technology which allow a proper interpretation of catch-effort data.

The study found that the core area of stock location within Western Australia is that currently fished by the pearl oyster fishery. Some stocks of possible commercial significance were located in deeper waters (20+m depth) off the Pilbara coast. However, the stocks located in the waters off the northern Kimberley coast were very limited and unlikely to be of commercial significance. It is likely that stocks also exist in deep water (35+m), offshore from the core Eighty Mile Beach fishing area, as this depth range was fished in the early history of the fishery. However, stocks at these depth are outside the scope of the modern fishery because of the safety requirements of the industry.

Trials with tagging pearl oysters resulted in the development of a tag suitable for use in monitoring the growth of pearl oysters larger than about 40mm. The placement of tagged oysters free on the bottom in a "dump" allowed good rates of recapture, providing the first data on natural growth rates of *P. maxima*. Application of the technique has provided a solid database on pearl oyster growth, although further recaptures are planned before formal analysis of the data.

Changes in the catch rate of pearl oysters in areas of the fishing grounds were examined for their potential to determine overall mortality rates, a large component of which would be the fishing mortality rate. However, the data show little or no decline in the catch rate of pearl oysters over a season in most areas, primarily because of the fishing method used by the industry. The assessment of fishing mortality rates will require the development of experimental methods, rather than the use of fishery data.

The examination of the reproductive cycle showed that there were differences in the spawning period between Broome and Exmouth Gulf. Spawning began earlier in Broome, with indications of two distinct spawning times (October and February), while there appeared to be only a single spawning in January in Exmouth Gulf. Genetic studies of pearl oysters revealed that there were different stocks of *Pinctada maxima* across northern Australia, from Western Australia to the Torres Strait. Pearl oysters within Western Australia were genetically similar and appear to form a single stock. Torres Strait and Northern Territory pearl oysters were not only genetically different to Western Australian pearl oysters, but were also genetically different to each other. There were also sufficient genetic differences between pearl oysters

from eastern and western areas of the Northern Territory for them to be considered as separate stocks.

The possibility of measuring recruitment to pearl oyster populations was examined using spat collectors and surveys of the abundance of naturally occurring spat. Spat collectors do not appear to provide a viable or cost-effective method of measuring recruitment, although they provided some useful data on the growth of small juveniles. Surveys of the abundance of naturally occurring spat provide a measure of spat abundance over a wider area than spat collectors, but still show high levels of variability in spat abundance within localized areas. Ensuring an adequate sample size may overcome much of this variability although the strategy for regular and adequate sampling of particular areas of the fishery needs further consideration if this technique is to provide a useful index to overall levels of recruitment.

The fishery logbook was expanded in some of the detail recorded and the method of data entry modified to retain computerised access to the detail recorded in the logbook. The database now records the data on depth, effort and catch for each dive conducted in the fishery, in at least 10 x 10 n.mile blocks. The data recorded in the logbooks, as well as observations made during field work on fishing vessels, provide a comprehensive understanding of the operations of the fishery. Analysis of data from the logbooks suggests that, overall, the stocks of *Pinctada maxima* in Western Australia are not fully exploited. However, any increase in the general level of exploitation would impact on the economics and farming programmes of the existing industry and these aspects must also be considered in determining the appropriate level of exploitation of the stock.

INTRODUCTION

This report outlines the results achieved through funding of project number 88/93 "An assessment of stocks of the pearl oyster *Pinctada maxima*" by the Fishing Industry Research and Development Council. Funding was provided by the Council, the predecessor to the Fisheries Research and Development Corporation, to the Western Australian Fisheries Department over the financial years 1988/89 to 1991/92. The purpose of the project was to conduct an examination of stock levels of pearl oysters in Western Australia and to develop an improved understanding of the species' biology. The fishery for the pearl oyster *P.maxima* provides the foundation for Australia's most valuable aquaculture industry (value of pearls produced in 1991 - A$120 million) but the quota management regime for the fishery is not based on a formal analysis of the stock or a comprehensive understanding of the biology of pearl oysters. The project was established to provide data which would allow the biology and degree of exploitation of the stock to be appropriately considered in the management of the pearl oyster fishery.

The original research proposal was to:

"Determine the distribution of pearl oyster stocks in W.A. waters and to estimate the abundance, size distribution, growth rates, rates of recruitment and natural mortality within these grounds. The reproductive status of stocks will also be examined with a view to determining the location and abundance of breeding stocks. Information on these aspects of oyster population dynamics is necessary to provide a proper scientific foundation for the allocation and variation of catch quotas within the pearl oyster fishery."

This original proposal was broken down into a series of objectives:

I). Stock Location: Determine the distribution, both geographically and by depth, of pearl oyster stocks in Western Australia.

II). Population Characteristics of Stocks: Estimate the abundance and size distribution of pearl oysters for particular segments of the Western Australian stock. Examine growth rates and natural and fishing mortality of oysters in selected areas.

III). Reproductive Status: Determine the sex ratios and reproductive condition of oysters within various sectors of the stock. This may be extended at a later date to an examination of the genetic identity of stocks, using electrophoretic techniques.

IV). Measurement of Recruitment: Develop a measure of annual recruitment to provide a database for consideration of breeding stock and environmental effects in stock-recruitment relationships.

V). Log Books: To continue to maintain log book records of diver catch and effort and to provide a knowledge base of pearl oyster biology and fishing fleet behaviour which will allow a proper interpretation of catch-effort data.

OUTCOMES OF OBJECTIVES

1). Stock Location

Outcomes for this objective fall into two areas - i). accumulating data on commercially fishable areas derived from log books, and ii). the results of surveys designed to locate stocks not currently subjected to commercial fishing.

i) **Log book data:**

The daily fishing logbook, operating since 1979, provides an on-going source of information about the location of commercially fishable stocks of pearl oysters. An upgraded logbook, developed through the FIRDC programme, provides catch rate details for each dive in the main fishing areas at the level of 10 x 10 n. mile blocks (Fig. 1). These blocks are further sub-divided into 2.5 x 2.5 n. mile blocks, with most skippers providing data at this level. The block data provide a fundamental base for understanding the area of operation of the commercial fleet and the sectors of the stock which are subjected to commercial fishing. The distribution of catch and effort in the main fishing grounds around Broome over the years 1989 - 1992 are shown in Figure 2 (a - d).

Summarizing the data for all years since the inception of the logbook to determine the centroid (the geographic centre) of the catch area for the main fishing area (Zone 2 - Cape Thouin to Sandy Cape) shows that the centroid of the catch moved north and east during the early-mid 1980s and then began moving south and west again in the late 1980s and early 1990s (Fig 3). These variations in the catching area probably reflect year-to-year differences in the main area of spat settlement as well as variations in the nature of the diving conditions.

ii) **Survey data:**

Surveys to obtain information about pearl oyster stocks outside the main areas of commercial fishing were conducted in two areas: the northern Kimberley region and the Pilbara region. Different approaches were used to obtain the data in each survey.

The Kimberley survey was operated by providing pearl oyster quota to individuals and companies wishing to carry out test fishing and ground surveys in the designated area. In return the companies and individuals provided records of their fishing and surveying results. The results of that survey, as published in a report to industry entitled "Exploratory survey of pearl oyster stocks in the northern Kimberley area of Western Australia, July 1989 - February 1990", are shown in Appendix 1.

The Pilbara region survey was conducted by a single research vessel, the Fisheries Department's RV "Flinders". Additional funding was provided from the Fisheries Research and Development Trust Fund to employ commercial pearl divers to operate from this vessel. The survey used echo-sounder and underwater television surveying to rapidly cover the area and identify likely areas of pearl habitat. These areas were then examined and fished by commercial pearl divers to provide catch rate and size frequency data. The results of the survey were provided to industry in a report entitled "A survey of the southern sector of the Western Australian pearl oyster fishery - July/August 1990" and are attached as Appendix 2.

2) Population Characteristics of Stocks

Outcomes of this objective were - i). the development of a technique for tagging and recapturing pearl oysters in the wild, ii). use of the tagging technique to obtain natural growth rate data for the development of a growth curve, iii). an examination of the value of oxygen isotope analysis in calibrating the "age" rings in pearl oyster shell and iv). the development of data analysis methods which provide preliminary information on fishing mortality.

i) *Tagging*: There have been few attempts to tag pearl oysters in the wild. Hynd (unpublished data) conducted tagging studies in the Torres Strait and Eastern Ground areas in the 1960's, but neither the methods nor the results were published. The techniques of tagging oysters on pearl farms generally require oysters to be held in panels or baskets, with the tag being applied to the container. These techniques require oysters to be held in a degree of confinement and, generally, in the environment of a pearl farm. To obtain data on un-confined pearl oysters in the natural environment, a new method of tagging had to be developed.

The development work was based on experience gained in the tagging of scallops, using individually numbered plastic (PVC and polyethylene) tags. The tags used on scallops were cemented on using cyano-acrylate glue ('supa-glue'). This adhesive worked well on the smooth surface of saucer scallop shells but its usefulness on the rougher surface of pearl oyster shells was dubious. Consequently two adhesives were tested - 1. cyano-acrylate glue and 2. an underwater setting epoxy (Fig. 4). Trials conducted in April 1989 showed that both glues worked on pearl oyster shells, but that the cyano-acrylate glue allowed tags to be applied more quickly than the epoxy.

The other aspect of developing a workable tagging and recapture procedure was to devise a technique which allowed a reasonable recapture rate of tagged oysters. Hynd's unpublished data notes that the tagged oysters in his studies were "dumped" (i.e. placed in a localized area in a specified locality defined by sextant readings of latitude and longitude). An adaptation of this dumping system was used in the present study, with oysters being placed on the bottom by hand on a strip of sea bed defined by Global Positioning System (GPS) readings of latitude and longitude. Oysters were recaptured by standard pearl diving techniques, using divers drifting over the strip defined by the (GPS) fixes. This system achieved recapture rates of tagged pearl oysters after 12 months at liberty of 11.7% (1989-90) and 30.6% (1990-91).

Additional data on the growth of small pearl oysters was obtained by placing them at specific underwater locations, marked by both a GPS fix and markers on the seabed. This approach was used because of the difficulty of detecting small pearl oysters by standard pearl diving methods and because of the more limited numbers available for tagging. The GPS fix was used to place divers in the general position of the seabed marker which was then located using standard underwater search techniques. Once the seabed marker was located, intensive searches by divers were conducted to locate tagged shell. Recovery rates (of live and recently dead but still tagged shell) for two trials conducted June - October 1989 and June 1990 to June 1991 were 8.4% and 3.9% respectively. Mortality rates of these small shell were probably fairly high, which would explain the relatively low recovery rates. In the two trials, recently dead but still tagged shell constituted 71% and 66% of the recoveries. Nevertheless, the method provided a means of obtaining some data on the growth of smaller pearl oysters, although the high levels of mortality may indicate a relatively high natural mortality level among small oysters.

ii) *Natural Growth Rate Data*: The trials of the tagging and recapture technique produced a reasonable amount of data on the natural growth rate of pearl oysters. Recaptures in June 1990 and 1991 of tagged pearl oysters released in June 1989 and

June 1990 provided annual growth increment data. Some pearl oysters tagged in June 1989 were not recaptured until June 1991, providing a 2 yr growth increment, with a total of 815 recaptures. The growth increment data are shown in Fig. 5. Further recaptures are planned to be made while tagged oysters are still alive and at reasonable abundance and the data will then be formally analysed.

iii) *Oxygen Isotope Analysis To Calibrate "Age" Rings*: The shells of pearl oysters have clearly visible "light" and "dark" bands which are obvious when the shell is sectioned along the dorso-ventral line. The general presumption is that these bands represent discontinuities or variations in the growth of pearl oysters and that the frequency for the discontinuity or variation is most likely to be annual. Possible sources of an annual discontinuity or variation include the seasonal highs or lows of water temperature, spawning, or reduced growth resulting from periods of low phytoplankton production.

Whatever the cause of the growth discontinuity or variation, the calcium carbonate laid down at the time the band is formed will have the isotopic characteristics of the water temperature and salinity at the time of the event. This is because the ratio of the isotopes of oxygen in calcium carbonate precipitated from seawater is a function of water temperature and salinity (Rye and Sommer, 1980). Because the water temperature varies in a cyclical manner while salinity remains relatively constant, determination of the apparent water temperature at the time of calcium carbonate formation provides a key to the timing of the band-forming event.

Samples for oxygen isotope analysis testing were taken from 8 pearl oysters from the Eighty Mile Beach area. Shells were sectioned on the dorso-ventral axis using a diamond saw blade and $CaCO_3$ samples obtained from selected bands by drilling into them with a fine dental drill. The samples were submitted to the CSIRO Division of Water Resources for analysis, who conducted the analyses for a commercial fee.

The results of the isotope analysis were highly variable, with "light" and "dark" bands having inconsistent oxygen isotope ratios (Table 1). This may be because there is no regular periodicity of band formation and that they are formed at various and irregular periods within the annual temperature cycle. Another possibility is that there was variable contamination of the samples with material from the adjacent band. Although the smallest available dental drill bit (0.7mm diam.) was used, considerable difficulty was experienced in controlling the positioning of the drill in the thinner growth bands. Slippage of the drill bit into the adjacent band would have produced contaminated samples and variable oxygen isotope ratios.

Further work is planned in the examination of oxygen isotope ratio samples of shell bands, using new procedures devised to eliminate sample contamination. Other techniques such as examing the concentrations of elements with temperature dependant incorporation (e.g. strontium) and internal making of the shell of tagged individuals with tetracyline may also provide data on the periodicity of the bands.

iv) *Analysis of Fishing Mortality*: The data available in the daily fishing logbook provided the possibility of an examination of the impact of fishing on pearl oyster populations. The approach used was to examine the change in catch rate against accumulated catch within the 10 x 10 n. mile grid squares. This technique, a version of the DeLury method of analysis of fish populations, allows the total fishable population to be estimated. The method is based on the assumption that catch rate will decline as pearl oysters are removed from the population and that the catch rate will fall to zero when all pearl oysters have been removed. Total catch will then equal the fishable population size. In practice there is a commercial lower limit to the catch rate, below which it is not economic to fish, but by extrapolating the slope of the decline in catch rate until it reaches zero, it is possible to estimate the total fishable population. Some of the change in pearl oyster numbers over a season will be due to natural mortality, but knowing the number removed from the area, allows an estimate of the fishing mortality to be made.

The results of some of the analyses are shown in Figs 6a - c. In most cases the mean daily catch rate for all vessels in the block shows little or no decline over the fishing period except in grid 3060 in 1991 and 1992. This indicates one of two possibilities - **either** the population is very lightly fished, so that the removal of pearl oysters has such a small impact on the fishable population that there is no significant decline in the catch rate - **or** all the implicit assumptions of the DeLury method are not fulfilled.

One of these assumptions is that the whole population is subjected to all the effort expended. Failure of the fishing method to fulfil this assumption is the most likely cause of the failure of the technique to indicate a significant decline in catch rate against accumulated catch. Pearling vessels commonly fish by a technique of "strip fishing", in which narrow swaths of bottom (approx. 20m wide) are fished sequentially, with each swath being fished only once or twice. Because vessels are constantly moving to fish new segments of the stock, catch rates remain high despite the removal of shell from the bottom. Prior to 1991, vessels positioned each drift relative to the previous drift by the use of radar positioning and marker buoys. The addition of GPS navigation equipment to all vessels in the fleet in the 1991 season has made the method of "strip" fishing even more efficient, although it is limited in its efficiency by the accuracy constraints of the navigation equipment and the capacity of skippers to steer the selected courses in strong tidal currents. Further research work to examine fish mortality and diver efficiency is planned but this will probably require a more experimental approach to the application of fishing pressure to a pearl oyster population.

3). Reproductive Status

Outcomes of the studies of reproductive status were: - i). The completion of a two-year study of the reproductive cycle of wild pearl shell at two locations on the Western Australian coast, ii). An examination of the genetic status of Australian stocks of *P. maxima*.

i) *Reproductive Studies*: This study was designed to provide a firm foundation for understanding the reproductive component of the recruitment processes of pearl oysters. Two sampling sites (Eighty Mile Beach and Exmouth Gulf) were selected to provide data from areas covering a large part of the range of *P. maxima* in Western Australia. Samples of 30 shell >160 mm shell height were taken on a two-monthly basis over two years from each site. The minimum shell size criterion was established to ensure that reasonable numbers of females were sampled. *Pinctada maxima* is a protandric hermaphrodite and the results of previous workers (Wada 1953, Rose *et al* 1990) indicate that, in this species, oysters first mature as males at around 110 - 120mm DVL. Development of a female sexual state does not occur until oysters are around 135- 140mm DVl and a 1:1 sex ratio is not reached until oysters are around 200mm DVL.

After collection, pearl oysters were macroscopically staged according to the criteria of Rose *et al.* (1990) and the visceral mass fixed in 10% formalin/sea water. After fixation a section of gonad in the region of the digestive loop was dissected out, sectioned and stained for microscopic examination.

The macroscopic staging indicated that the reproductive season of *P. maxima* over the range Eighty Mile Beach to Exmouth Gulf was in the period October - November through to March - April. The more detailed microscopic examination pointed to a longer spawning period in the Eighty Mile Beach area, with indications of two distinct spawning times (October and February). In Exmouth Gulf, however, there appeared to be only a single spawning in January. The analysis of the sections was conducted as an honours thesis study by one of the technical staff attached to the programme (A. T. Hancock) and the detailed aspects of the analysis are recorded in his thesis (Hancock 1993).

ii) *Genetic Status of Australian Pinctada maxima*: Tissue samples of *P. maxima* from five localities (Fig. 7), selected to cover a large proportion of the Australian range of *P. maxima*, were subjected to electrophoretic examination. The samples from Oxley I. and Torres Strait were provided by Kathy Colgan (B.R.R.) and the sample from Flat Top Bank was provided by Ian Knuckey (N.T. Fisheries). The electrophoretic work was carried out by Dr M. Johnston (Zoology Dept., University of Western Australia) and the results were published in August 1993 (Johnson and Joll, 1993).

In summary, the results (Fig 8) showed that there are several sub-stocks of *P. maxima* in northern Australian waters, with Western Australian pearl oysters in the area from Exmouth Gulf to Eighty Mile Beach forming a single, genetically connected sub-stock. Pearl oysters in Northern Territory waters were genetically different to Western Australian oysters and Torres Strait oysters were different to both Northern Territory and Western Australian oysters. Significant genetic differences were also found between populations in the two areas sampled in the Northern Territory. These findings have important implications for the management of Australian pearl oyster fisheries and the selection of broodstock for use in hatchery programmes.

4). Measurement of Recruitment

Two techniques were tested for their usefulness in providing a measure of recruitment into the pre-fishery stages - i). Artificial spat collectors, and ii). "Piggy-back" spat.

i) *Artificial spat collectors*: Artificial spat collectors were tested over the 1989/90 and 1990/91 spawning seasons. In the 1989/90 season, collectors were set out at several sites in the Eighty Mile Beach area as well as in Exmouth Gulf (Fig 9a & b). However, because of limited resources, collectors were restricted to the Eighty Mile Beach sites in the 1990/91 season.

Various designs and substrates were used at the two localities (Fig 10a & b). The design differences between the collectors used at Eighty Mile Beach and Exmouth was because of the differences in physical conditions in the two localities. The Eighty Mile Beach area has a fairly firm substrate, but is reasonably exposed to storm conditions. The design considerations for this locality were to reduce drag by sloping the faces of the collectors and providing heavy anchoring weights and a low centre of gravity to improve stability. The Exmouth area, on the other hand, is very sheltered but has a fairly soft substrate. The collectors at this locality were mounted on star pickets to prevent them sinking into the bottom, while the drag considerations on collector shape were minimal.

The various substrates used in the 1989/90 trial were chosen on the basis of the likelihood that they may represent suitable settlement substrates for pearl oyster larvae. Monofilament fishing net is widely recognized as a suitable substrate for scallop larvae (Ventilla 1982, Hortle and Cropp 1987, Sumpton *et al.* 1990) and has been used with some success for pearl oyster larvae (Scoones pers. comm.). Scallop shells were used to provide a substrate which may emulate the shells of adult pearl oysters, as spat are encountered attached to the shells of adult pearl oysters. The collector cages were encased in 25mm polyethylene ("Nylex" brand) mesh to allow the flow of water while minimizing the entry of some predators of spat such as fish and crabs . The monofilament mesh was packed in plastic mesh 'onion bags' (approx. 10mm mesh), which provided another protective barrier against some predators. At Eighty Mile Beach, 100g of monofilament was packed into an onion bag, but at Exmouth two densities of monofilament were also tested, by packing onion bags with either 100g or 400g of monofilament.

The collectors were set out in pairs at each of the sites at the two localities. Because of the size and shape of the Exmouth spat collectors, it was possible to combine both substrates in each collector pair, with the positions of the substrates reversed to consider the effects of shading (Fig. 10b). The size and shape of the Eighty Mile Beach spat collectors did not permit combining the substates in each collector and one collector containing each type of substrate (monofilament or scallop shell) was set out at each site.

Based on the experience gained in the 1989/90 trials, a new range of substrates was tested in the 1990/91 trials (Fig. 10c). Substrates tested were those that had been effective in catching spat in the previous year's trial, as well as adaptations of these substrates. The Nylex mesh used to protect against the entry of larger predators was found to collect pearl oyster spat and was used inside onion bags in the 1990/91 trials. The 400g bags of monofilament were not found to be satisfactory in the Exmouth trials, due to clogging by fouling organisms and sediment, and only 100g bags of monofilament were again used at Eighty Mile Beach in 1990/91. Pearl oyster shell was also tested, as the scallop shell had been found to be unsuccessful as a spat settlement substrate.

Because the buoy ropes had been found to catch pearl oyster spat, particularly near knots and in the grooves generated by the lay of the rope, onion bags containing knotted rope were also tested. Polyethylene film rope was used as literature reports (Ventilla 1982, Naidu and Scalpen 1979) indicated that such ropes made of this material may be particularly suitable for bivalve settlement substrates. The settlement on the buoy ropes was also noted to be associated with algal growth on the ropes. It was not known if this was due to active selection by settling larvae or because of reduced predation as a result of the protection provided by the surrounding algae. To simulate the protective effect of the algae, a rope fibre (tanikalon) was woven into the lay of the rope (Fig 10d). Most algal growth in the 1989/90 trials had been near the surface because of the higher light levels in this part of the water column, but the effects of depth were also examined by placing three bands of tanikalon on the buoy rope - one just above the collector (bottom), one at mid-water (mid-water to surface depending on tide) and one at the surface. To further consider the value of buoy ropes as settlement substrates, different buoy ropes were used on each pair of collectors. Standard polypropylene float rope (as used in the 1989/90 trials) was used as well as polyethylene film rope, with the tanikalon being woven into the film rope.

The results of the various trials are shown in Table 2a-b. Although there were some differences between the various substrates, the main feature of the results is the generally low catch of *P. maxima* spat. In some cases the catch may have been affected by a break-down in the integrity of the fish and crab predation barriers in the collectors. However, the settlement of more substantial numbers of the "bastard" pearl oyster *P. albina* and the winged pearl oyster *Pteria penguin* on all of the substrates (except scallop shell), suggests that other factors may affect the settlement of *P. maxima* on the collectors. These factors may include i). inappropriate collector design, ii). high specificity of the larvae for settlement substrates or iii). poor placement of the collectors with respect to areas of larval abundance. Given the much higher catches of spat by collectors being used by a commercial pearling company on one of its farm leases in Roebuck Bay, which are of a similar design as the Eighty Mile Beach collectors and using one of the same substrates (monofilament) (Scoones pers. comm.), it seems likely that the main cause of low catches is a lower larval abundance at the Eighty Mile Beach test sites than on the farm site. Another possibility is the timing of the setting of the collectors with respect to larval settlement. Setting the collectors too early, thereby allowing the prior growth of fouling organisms, leads to low numbers of spat (Scoones, pers. comm.) However, the 1990/91 collectors were set out in mid-December 1990, a similar time to the setting out of the collectors on the farm site, without any obvious increase in spat numbers.

The generally low settlement rates of *P. maxima* spat on the collectors suggests that they were not a very practical means of measuring recruitment indices. Moreover, with the low numbers of spat caught on the collectors in the present trial, it would require a substantial number of collectors to be able to detect real differences in settlement rates between areas. However, because the cost of installing the collectors in relatively remote localities is quite high, and the time taken to sort the material considerable, it is not practical to install them in large numbers. Furthermore, the capacity of any single collector to properly represent the recruitment processes of the adjacent area is dubious. Pearl divers report wide variations in the abundance of spat between very localized areas of the fishing grounds (within 200m) and the capacity of a small number of collectors to integrate this variation is probably very limited.

Although the spat collectors were not considered to be useful for measuring recruitment into the pre-fishery stages, the sizes of spat caught on the collectors provides a guide to the ages of spat in the wild. The size frequency distribution of spat caught in the 1989/90 and 1990/91 trials showed a modal peak around 25-30mm in 1989/90 and around 15-20mm in 1990/91 and maximum sizes in both years around 35-39mm (Fig. 11). These data indicate that spat of less than 40mm in April are a maximum of 5-6 months of age (i.e. 0+ age class).

ii) *"Piggy-Back" spat*: Spat of *P. maxima* sometimes occur attached to culture-size (120-160+mm) shell brought up by divers in the commercial fishery and are colloquially called "piggy-back" spat (Fig.12). Although only small numbers of spat are found (usually less than 1 per 100 culture oysters), it was assumed that the number of "piggy-back" spat attached to larger shell represented a fixed proportion of the number of spat settling in an area. Because of the wider area covered in commercial fishing operations, however, this technique was considered likely to be better at integrating localized recruitment variations than spat collectors. An examination of the numbers of "piggy-back" spat attached to culture-size shell was conducted to see whether it could provide a useful recruitment index. "Piggy-back" spat are sometimes found on pearl oysters larger and smaller than the sizes sought for pearl culture, but only "piggy-back" spat attached to culture-sized shell were counted. This is because the effort of divers is directed at culture-sized shell and the rate of "piggy-back" spat determined by examining only culture-sized shell is unbiased by diver behaviour.

Preliminary trials of the technique were carried out on one vessel during April 1990 and these were expanded in the March - April period in the 1991 and 1992 seasons. Examination of the size frequency data for each of the years indicated the presence of two size classes in the spat from Eighty Mile Beach during March - April in all years (Fig. 13). The modal value of the smaller size class was around 15 - 20mm and the upper size limit of the mode was around 40mm, suggesting that this group of spat was equivalent to the spat found on the collectors (Fig. 11). The larger size class had a modal value of around 50 - 60mm and an upper size limit of around 70mm. The difference in both modal value and upper size limit of the two classes approximates the annual growth increment of oysters of initial DVL of 20 - 30mm determined from the tagging studies (Fig. 5), suggesting very strongly that the larger size class of spat represents the previous year class (i.e. 1+ animals). Spat size frequencies from the Lacepede Islands area showed only a single modal peak at around 40 - 45mm, suggesting either earlier settlement or faster growth, or both, in this area.

On the basis of the size-frequency data, the "piggy-back" spat rate data for spat up to 70mm DVL from Eighty Mile Beach are presented for two size-classes (= year classes?), as well as overall. The Lacepede Islands area data (Blocks 2959 and 3060) are only presented overall, as spat up to 70mm from this area appear to represent a single year class. The data (Table 3), for dives catching >50 culture shell, show a high degree of variability in the mean rate of "piggy -back" spat from block to block and year to year. There was also a high degree of variability in the "piggy-back" spat rate from dive to dive, which is reflected in the large standard deviations in Table 3. This variability was apparent even with dives which were within a short distance (200-400m) of each other.

The high degree of variability in the rate of "piggy-back" spat on culture oysters affects the level of confidence with which the mean rate of "piggy-back" spat can be determined. Increasing the number of drifts, and pearl oysters, examined improves the level of confidence in the mean rate, but the high level of variability in the base data limits the precision with which the mean rate can be measured. The percentage accuracy for the estimate of the mean within one standard error improves with increasing numbers of dives and pearl oysters sampled, but was not better than 10% for even very large members of dives and pearl oysters (Fig 14). Although there was a fair degree of variation in the percentage of the precision of the mean within one standard error, the data indicate that about 30-40 dives and about 5 - 6000 pearl oysters need to be sampled to obtain an estimate of the mean rate with a precision for one standard error of about 20%.

While sampling "piggy-back" spat may cover a wider area than that likely to be represented by artificial spat collectors, the data still indicate that there is a high degree of patchiness in spat settlement, even on this larger scale. The high degree of variability which this patchiness generates in the "piggy-back" spat limits the usefulness of "piggy-back" spat rate data for comparing levels of recruitment from year to year and area to area, as the degree of uncertainty in the precision of the mean value means that only really major changes in the levels of recruitment will be able to be detected with confidence. Despite this problem with the precision of the mean, the data collected over the period 1990-92 showed that there were sufficient differences in the "piggy-back" spat rate in the various blocks sampled over this period for significant differences in the mean rate in different blocks to be detected (analysis of variance, $P < 0.0001$).

Although "piggy-back" spat settlement rates appear to be capable of detecting variations in settlement rates of pearl oysters - or at least the larger variations - there are still some problems in the general usefulness of the data for a recruitment index. These problems arise because of the need to use commercial pearling vessels as the sampling platform, because these provide coverage of a much larger area and a much larger number of dives and pearl oysters than would be possible with research diving. However, the fishing areas which commercial vessels work varies from year to year because of variations in the abundance of pearl oysters or the nature of the diving conditions, so it is not possible to regularly sample particular 10 x 10 n. mile blocks. Even if the same blocks are sampled, a sample of 30 - 40 dives or 5 - 6 000 oysters may only reflect the spat settlement levels of a small fraction of the available pearl oysters habitat within a block. In addition, the areas sampled within a block may vary from year to year. These sampling problems make it difficult to obtain comparable data from year to year for particular blocks and, where blocks are not sampled or the areas sampled are too small to be wholly representative, the overall data cannot provide a reliable guide to overall recruitment.

Despite the problems with "piggy-back" spat rate measurements, this technique appears to offer a better chance of successfully measuring recruitment rates in pearl oyster populations than spat collectors. However, further consideration needs to be given to the appropriate sample sizes and the sampling strategy so that data are comparable from year to year and provide a better overall assessment of recruitment.

5). Log Books

Outcomes in this section were: i). modification of the data entry procedures to maintain detailed records of each dive, ii). compilation of a unique vessel identifier list for all log book records back to 1979, and iii). development of a photographic record of all current vessels in the fishery and a register of the design and equipment features which may have a bearing on the fishing power of vessels.

i) *Log book data and data entry*: The log book provides the core catch per unit effort (CPUE) data for considering the the status of the fishery on the main fishing grounds as well as documentation on the catch for quota recording purposes (Figure 15). Prior to 1989 the catch and effort data for each drift were aggregated before entry to the total catch and total effort for a day within any one 10 x 10 n. mile block. This form of entry was suitable for overall catch and effort data, but it lost the capacity to fully quantify the fine-grained behaviour of the fishing fleet. Expanding the data base to record the results of each drift dive has not reduced the compatability of current data with past data, as the current data simply has to be aggregated to put it into a compatible format, but this new form of data entry provides increased analytical power.

The data series from the logbooks (Fig. 16) shows that CPUE on the Zone 2 grounds has remained relatively steady over the period 1983 to 1992 at around 20 culture shells per diver hour, in the face of an increase in total catch from around 290 000 shells in 1984 to around 460 000 shells in 1992. Similarly the CPUE for Zone 3 has remained relatively constant over the period from 1988 (when the zone began to experience substantial sustained fishing pressure) to 1992.

One of the major difficulties in interpreting the fishery data comes from the method of operation of catching vessels, which serially fish patches of pearl oysters and then move to a new patch. This method of fishing maintains a relatively steady CPUE despite decreasing total stock levels. In view of the difficulties with CPUE analysis, the alternative is to examine the pattern of fishing over a time series for indications that the total stock is being eroded, even though CPUE is remaining relatively static. Indications of total stock erosion may include a movement in the location of catching area of the fishery so that areas fished in the past are no longer fished or, because the 10 x 10 n. mile grids are fairly coarse and cover a range of depth categories, an increase in the average depth from which oysters are caught.

Because of the aggregation of data in the log books prior to 1990, it is only possible to examine any changes in average depth of the annual catch over the period 1990 to 1992. These data (Table 4) show that for Zone 2 the mean depth of the catch increased in from 1990 to 1991 and then deceased again in 1992, while the mean depth in Zone 3 increased marginally over the period. The movement of the location of the centroid of the catching area of the fishery over the period 1979 to 1991 (Fig.3) shows that over this period the centroid of the catch has returned to areas which were previously fished, indicating that areas fished in the past continue to be useful contributors to the catch. Taken together, the data indicate that the pearl oyster fishery is operating within the bounds of the productivity of the stock in the area of Zones 2. The main area of activity in Zone 3 falls largely within one 10 x 10 n.mile block, but the fact that this small area has been repeatedly fished since 1988, with no apparent decline in total catch or catch rate and only a marginal increase in the mean depth from which the catch is taken, also indicates that it is being fished within the bounds of its productivity.

ii) *Compilation of a unique vessel indentifier list*: Part of the value of the fishing log book database is the capacity to examine changes, particularly in catch per unit effort, with time. However, over the period of the log book there have been many changes in the composition of the fishing fleet. Because of the differing capacities and equipment of these vessels, it is likely that they have different fishing powers and efficiencies of operation. It is essential that the impact of these changes in vessel and vessel technology are properly recorded in the fishing database so that the impact of vessel changes on fishing efficiencies can be kept under review. Records in the database up to 1988 were kept under the vessel's pearling boat number. However, this number is not a unique identifier, as boat numbers are re-issued to new vessels when the original holder leaves the fleet. Although a list of names of vessels holding particular pearling boat numbers was maintained, some vessels in the fishery have re-used the names of earlier vessels. To avoid confusion in referring to vessels in the database, a unique identifier list was compiled which identifies each vessel in the fishery since the inception of the logbook.

iii) *Development of a Photograhic Record and Register of Design and Equipment Features*: This record is designed to be used in parallel with the vessel identifier list to provide the detail necessary for identifying possible technological or design features which may affect vessel fishing power or diver efficiency.

CONCLUSIONS

1. Stock Location

The surveys of areas outside the main fishing grounds around Broome indicated that beyond the main Broome grounds, and the areas around Onslow and Exmouth Gulf, the overall abundance of *P. maxima* was low. There were indications of potentially commercially viable levels of abundance of culture shell in deeper waters (20+m) off the Pilbara coast. However, the abundances observed in the northern Kimberley area did not indicate commercially viable stock levels in that area.

The logbook data show the importance of the two main areas around Broome - the Lacepede Channel north of Broome (Block 3060) and a range of blocks off Eighty Mile Beach to the south of Broome. The importance of particular areas varied from year-to-year and this variation appears to reflect local variation in the strength of recruitment in different years as well as physical factors affecting the capacity of divers to operate in some areas. The increases in catch and effort in the Wallal area in the early 1990s indicate that grounds in this area are returning to being productive following their devastation by a cyclone in the late 1970s. The shift of the centroid of the fishery further south in the late 1980s and early 1990s partly reflects this improvement in the Wallal grounds. However, the main factors apparently leading to a shift further south of the centroid of the fishery are a renewed abundance of pearl oysters in the area to the south of Mangrove Pt. (Cape Missiessy) and an improvement in the physical factors affecting the operations of divers in this area.

2. Population Characteristics of Stocks

The various trials carried out in this section showed that individual tagging of pearl oysters was feasible and provided the first data on natural growth rates. A longer time series of growth data over a wider range of sizes and over a number of years is planned to be collected before full analysis and publication. However, the techniques trialled here, and the initial results, provide a foundation for this work to proceed.

The oxygen isotope analysis indicated that this technique could prove useful in determining the periodicity of the bands in pearl oyster shells, once the technique of obtaining un-contaminated samples has been perfected. Examination with an electron microprobe (which does not require manual removal of the sample material) of the concentrations of elements which have temperature dependent incorporation into the shell (e.g. strontium) may also be useful - to either corroborate the isotope data or to provide an alternative technique if the sample contamination problems of oxygen isotope analysis remain intractable. Direct internal marking of tagged shell (e.g. with tetracycline or strontium) and recapture of the shell after a known interval might also provide a means of determining the periodicity of the internal bands.

The technique of analysing fishing mortality by treating the catch data in the 10 x 10 n. mile blocks as depletion fishing indicated that, while this approach may appear to work in some blocks, in other blocks the practice of serially 'strip-fishing' invalidated some of the requirements for this technique to be validly used. Determination of the impacts of fishing mortality on pearl oyster populations will require a more direct experimental approach, which will control the application of fishing pressure in a way which does not invalidate the DeLury technique.

3 & 4. Reproductive Status And The Measurement Of Recruitment

The results of the reproductive studies, in combination with the size-frequency data of spat from the artificial spat collectors and "piggy-back" spat, provides the basis for understanding the origins and ages of recruits detected in the population. The reproductive studies provide a sound basis for understanding the times of spawning and recruitment along the Western Australian coast. This in turn forms the basis of an understanding of the ages of recruits detected in the 'piggy-back' spat sampling and on the artificial collectors. The growth and age data provided by this indirect approach are extremely valuable, as measurement of the growth of spat by tagging is difficult because of their small size and high rate of predation.

The measurement of "piggy-back" spat rates has the potential to provide an index of the strength of recruitment, although the wide variation in "piggy-back" spat rates over small areas indicate that it may not produce a reliable index unless samples are sufficiently large and sufficient areas are sampled. The development of a reliable recruitment index, together with a knowledge of the time between recruitment as spat and recruitment to the fishable size groups, provides the potential for a technique to forecast stock abundance. These forecasts could provide the method for a scientifically-based variation in quotas from year-to-year.

5. Log Books

The log book data forms the core data for considering the status of the fishery. Examination of the changes in CPUE has previously formed the core of the analysis of the status of the stock. However, the full time series of logbook data also provide the details of areas from which oysters were fished, allowing analysis of the movements in the catching area over time. The changes instituted in the data entry procedure since 1990 also allow the depth profile of the fishery to be examined.

The results of the various analyses indicate that, with Zones 2 and 3, the fishery is operating within the bounds of the productivity of the stock. Catch per unit effort has remained relatively constant over time, even despite an increase in total catch. The centroid of the catch has moved around within the general fishing area of the fleet but has returned to areas previously fished, rather than constantly moving to new areas to maintain CPUE. Finally, although the time series is shorter, the mean depth from which oysters have been taken has been relatively static, indicating that the fishery has not moved into deeper waters within the 10 by 10 n. mile blocks in which data is recorded.

The data do not indicate the degree to which the stock is exploited, other than to show that it is exploited at a level less than or equal to its productivity. From a biological perspective there may be scope to further increase the degree of exploitation without affecting recruitment, although it is not possible to predict the degree of further exploitation which could be tolerated by the stock. Any more permanent increase in exploitation from current levels, other than small year-to-year increases to exploit annual variations in recruitment, would need to be on a stepwise basis, with a period of probably around 5+ years at each step to allow the stock to stabilize at the new level of exploitation.

Any increase in exploitation is, however, likely to reduce CPUE, as a larger fraction of the available stock will be taken. This will lead to an increase in the time taken to catch the shell for the first seeding in July, as well as the costs of taking the shell. Alternatively, or in addition, the fishing fleet may be forced to expand into areas further south of Broome or into deeper waters to maintain CPUE. Expansion further south would increase the distance between dumps and holding grounds for operated oysters or require the establishment of new holding areas. An increase in either the maximum or the average depth from which the catch is taken may compromise the improved safety standards of the industry. These aspects of any general increase in the level of exploitation of the stock would be contrary to some of the desirable management outcomes for the fishery, which include the taking of oysters at economic catch rates and in water depths consistent with diver safety and the capture of the stock for first seeding within a programmed time schedule compatible with the rest of the year's farming activities. Thus, while the analysis of the fishery data indicate that the pearl oyster stock in Western Australia is currently exploited to a level which may allow for a general increase in the level of exploitation without affecting recruitment, there are practical implications for the operations of the whole industry which may indicate that the appropriate level of exploitation for the best practical and economic operation of the fishery is lower than the maximum sustainable yield.

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Table 1. Results of oxygen isotope analysis

Pearl Oyster	Band Type	Delta O^{18}	Calculated Temperature*
1	Light	-0.56	23.2°C
2	Dark	-1.05	25.6°C
3	Dark	-0.63	23.6°C
4	Light	-1.26	26.7°C
5	Dark	-0.08	20.9°C
6	Light	-0.00	20.6°C
7	Light	-0.60	23.4°C
8	Dark	-0.77	24.2°C

* Based on the formula given by Grossman E.L., 1982. Stable isotopes in live benthic foraminifera from the southern California borderland. PhD Thesis, Univ. Southern California (cited in: Kalish J.M., 1991. Oxygen and carbon stable isotopes in the otoliths of wild and laboratory-reared Australian salmon *(Arripis trutta)*. Mar. Biol. 110: 37 - 47). Salinity used for standard mean ocean water: 35.0‰.

Table 2a

P. maxima SPAT COLLECTOR RESULTS
(6 October 1989 - 5 April 1990)

	SUBSTRATE TYPE	NUMBER OF *P. maxima* SPAT			TOTAL FOR SUBSTRATE TYPE
		La Grange Bay	Tryon Point	Patterson Shoal	
1	Monofilament Net (Collector A)	12	1	1[1]	14
2	Scallop shell (Collector B)	0[1]	0[1]	0	0
3	Nylex Mesh (A + B)	2	0	0	2
4	Polypropylene rope/floats (A + B)	3	3	1	7
TOTAL		**17**	**4**	**2**	**23**

1 Exterior mesh of collector cage broken open

SPAT COLLECTOR RESULTS - EXMOUTH GULF
(8 JANUARY 1990 - 14 MAY 1990)

SUBSTRATE TYPE	**NO. OF *P. maxima***
Shark Mesh	2
Nylex	1
Scallop shells	0
TOTAL	3

TABLE 2b

P. maxima SPAT COLLECTOR RESULTS
(11/12 DECEMBER 1990 - 23/24 APRIL 1991)

SUBSTRATE TYPE (Paired collector cages)	NUMBER OF *P. maxima* SPAT			TOTAL FOR SUBSTRATE TYPE
	La Grange Bay	Tryon Point[2]	Patterson Shoal[2]	
1 Nylex panel mesh	1[3]	0	0	1
2 Monofilament New	0[3]	0	2	2
3 Knotted P.E. film rope	3[3]	0	4	7
4 Pearl shell	1	0	0	1
5 Exterior of collector:				
- a. metal frame	3	0	0	3
- b. nylex mesh	0	0	1	1
5 Polypropylene (orange rope)	1	3	0	4
7 Polyethelene film rope:	3	2	1	6
- a. bottom	0[4]	0[4]	1	1
- b. middle	1	1	1	3
- c. surface	1	0	1	2
8 Tanikalon covered areas of p.e. film rope				
9 Floats	0	0	0	0
TOTAL	14	6	11	31

1 Exterior mesh of one collector cage broken
2 Exterior mesh of both collector cages broken open
3 Protection bags torn open (2 panel mesh, 3 shark mesh, 4 rope)
4 Bottom tanikalon bunch sunk onto collector and abrading.

TABLE 3: MEAN RATE (± S.D.) OF "PIGGY-BACK" SPAT PER CULTURE SHELL (≥50 SHELL PER DRIFT)

BLOCK	SPAT SIZE CLASS	YEAR 1990	1991	1992
2959	0-39			-
	40-70			-
	0-70			0.011 (0.010)
	(dives) (oysters)			(10) (626)
3060	0-39			-
	40-70			-
	0-70			0.009 (0.010)
	(dives) (oysters)			(157) (14 261)
4056	0-39		0.002 (0.004)	
	40-70		0.003 (0.006)	
	0-70		0.004 (0.008)	
	(dives) (oysters)		(18) (1 664)	
4057	0-39	0.044 (0.030)	0.003 (-)	
	40-70	0.010 (0.011)	0.000 (-)	
	0-70	0.054 (0.032)	0.003 (-)	
	(dives) (oysters)	(16) (1 181)	(1) (60)	
4156	0-39		0.002 (0.010)	0.004 (0.006)
	40-70		0.002 (0.006)	0.005 (0.011)
	0-70		0.004 (0.011)	0.009 (0.014)
	(dives) (oysters)		(95) (8 096)	(29) (3 195)
4255	0-39			0.014 (0.010)
	40-70			0.006 (0.006)
	0-70			0.019 (0.012)
	(dives) (oysters)			(10) (860)
4256	0-39	0.003 (0.006)		
	40-70	0.002 (0.005)		
	0.70	0.005 (0.007)		
	(dives) (oysters)	(24) (2 285)		
4353	0-39	0.006 (0.007)		
	40-70	0.011 (0.013)		
	0-70	0.018 (0.017)		
	(dives) (oysters)	(20) (2 178)		
4354	0-39		0.003 (0.006)	0.004 (0.006)
	40-70		0.008 (0.009)	0.005 (0.007)
	0-70		0.011 (0.010)	0.009 (0.009)
	(dives) (oysters)		(19) (2 445)	(59) (5 848)
4355	0-39	0.011 (0.007)		0.002 (0.004)
	40-70	0.009 (0.013)		0.003 (0.005)
	0-70	0.020 (0.017)		0.005 (0.006)
	(dives) (oysters)	(9) (1 019)		(34) (4 486)
4454	0-39		0.000(-)	0.006 (0.009)
	40-70		0.012 (0.010)	0.005 (0.006)
	0-70		0.012 (0.010)	0.012 (0.009)
	(dives) (oysters)		(16) (1 778)	(42) (5 631)

TABLE 4: MEAN DEPTH (M) FROM WHICH PEARL OYSTERS WERE CAUGHT IN ZONES 2 AND 3: 1990 - 1992.

	1990	1991	1992
ZONE 2	15.34m	16.16m	13.90 m
ZONE 3	18.02m	18.51m	19.33m

Fig. 1 Logbook chart page showing 10 x 10 n. mile blocks in 2.5 x 2.5 n. mile sub-divisions.

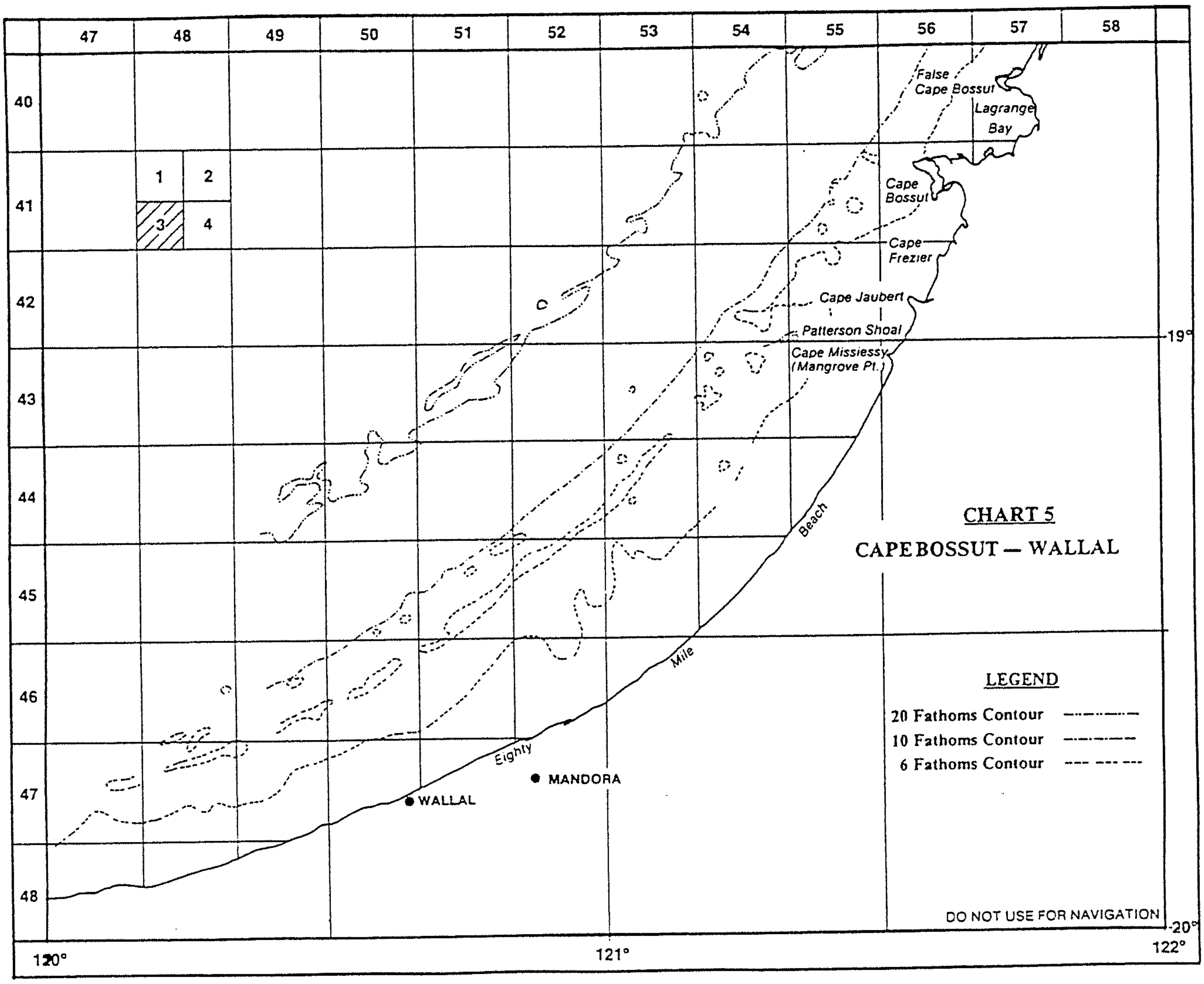


Fig. 2 Distribution of catch and effort in the fishing areas around Broome.
a) 1989

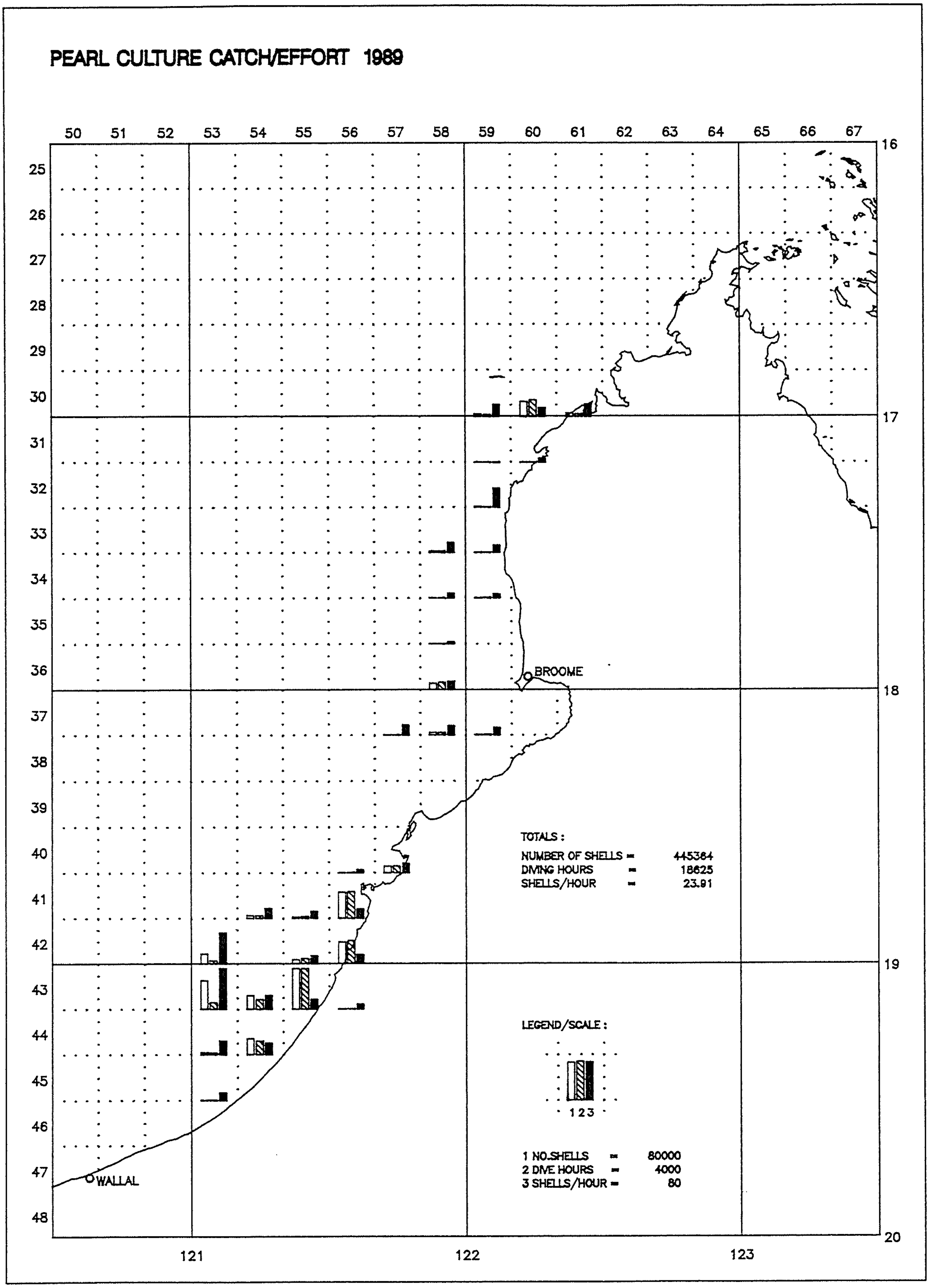


Fig. 2 Distribution of catch and effort in the fishing areas around Broome.
b) 1990

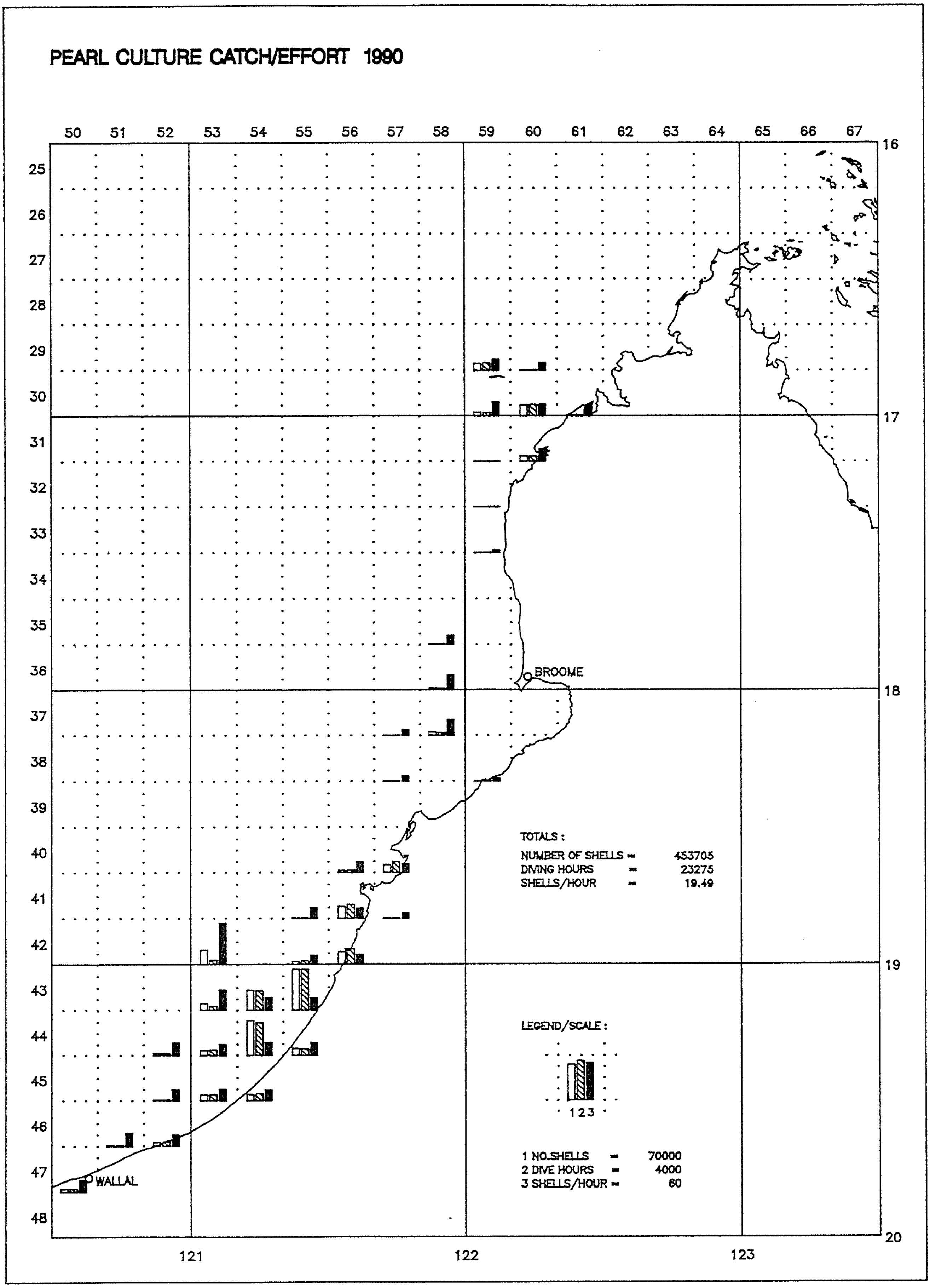


Fig. 2 Distribution of catch and effort in the fishing areas around Broome.
c) 1991

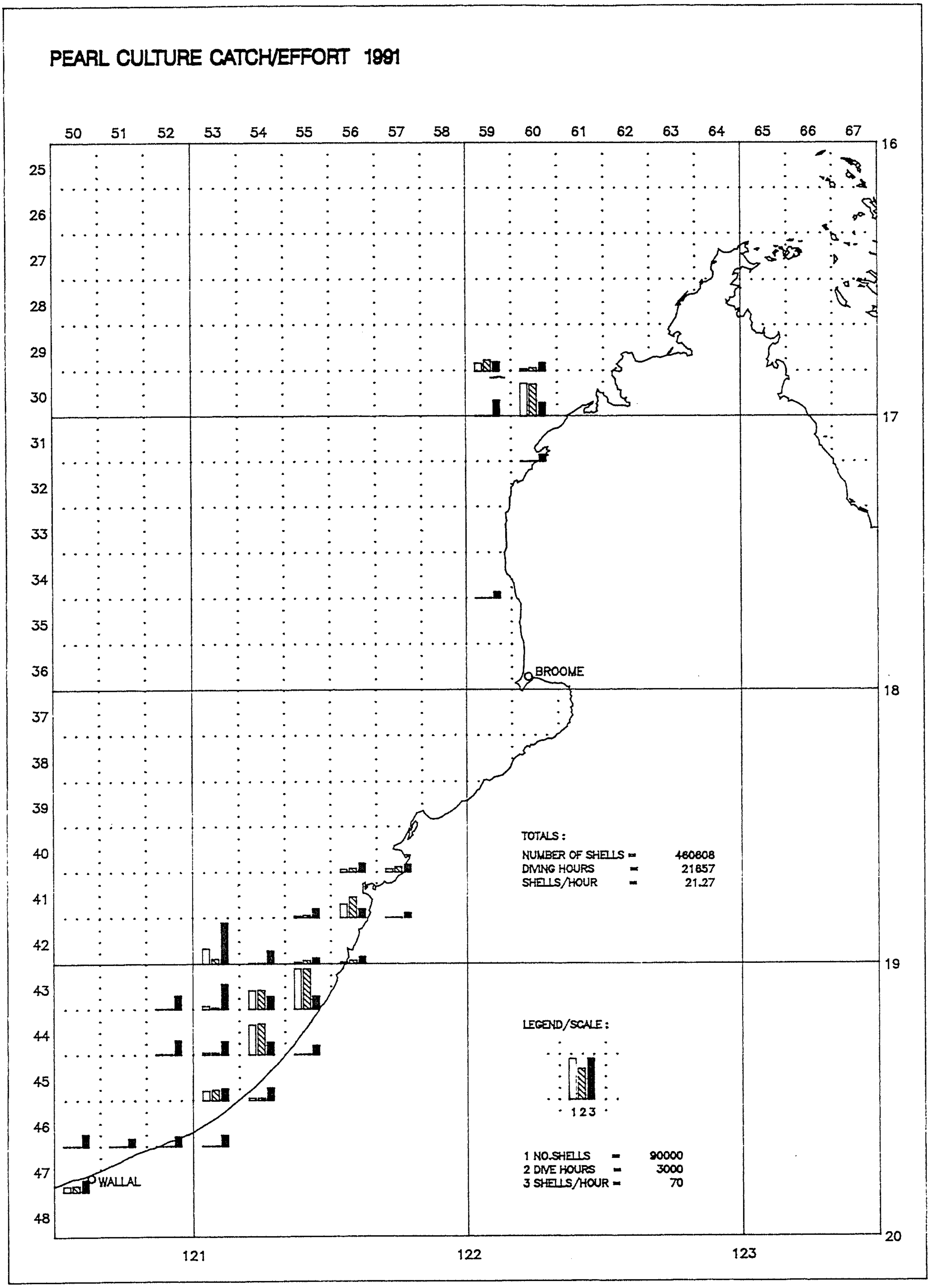


Fig. 2 Distribution of catch and effort in the fishing areas around Broome.
d) 1992

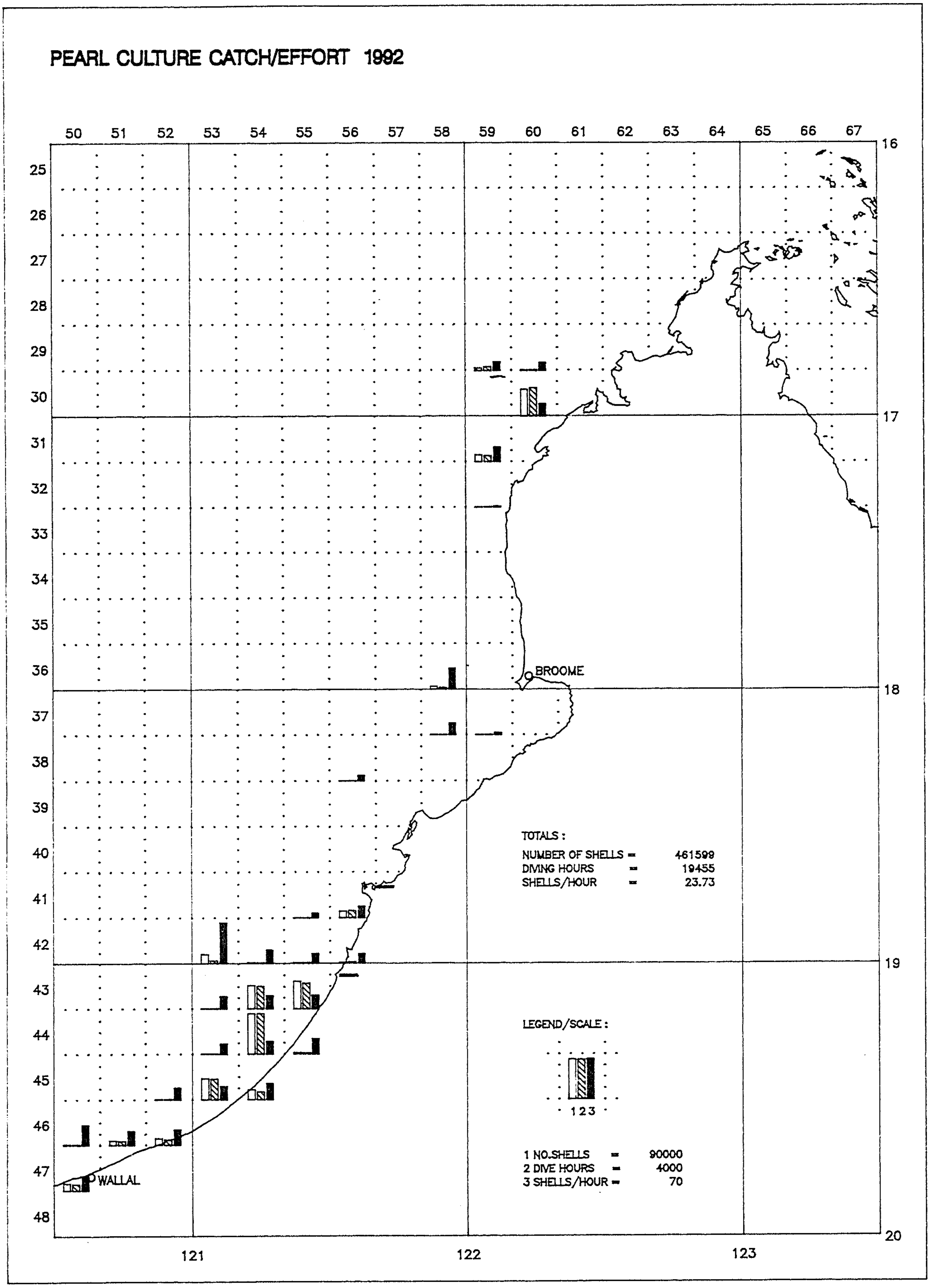


Fig. 3 Position of the centroid (geographic centre) of the catch of pearl oysters taken from Zone 2 (Cape Thouin - Sandy Cape), 1979 - 1992.

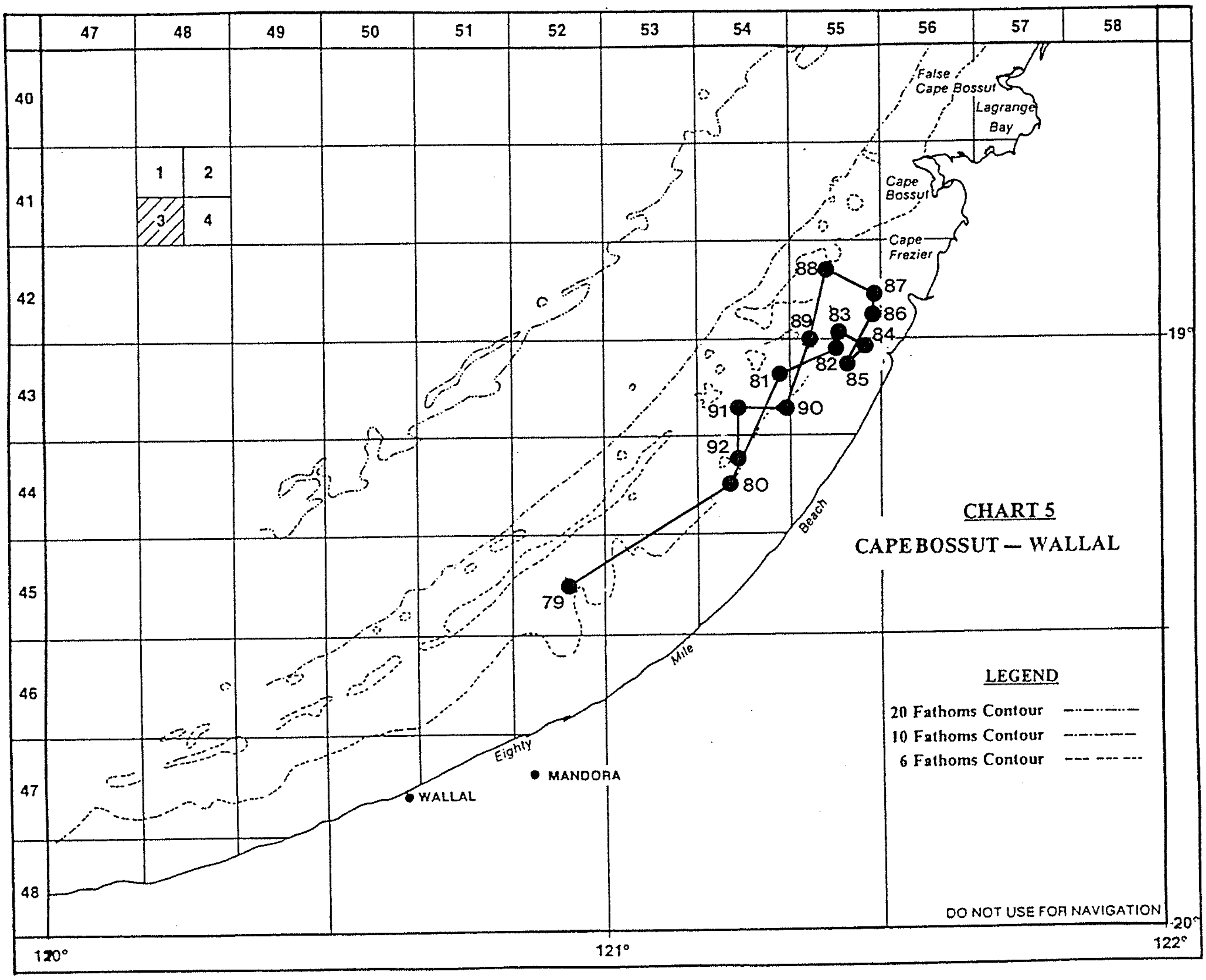
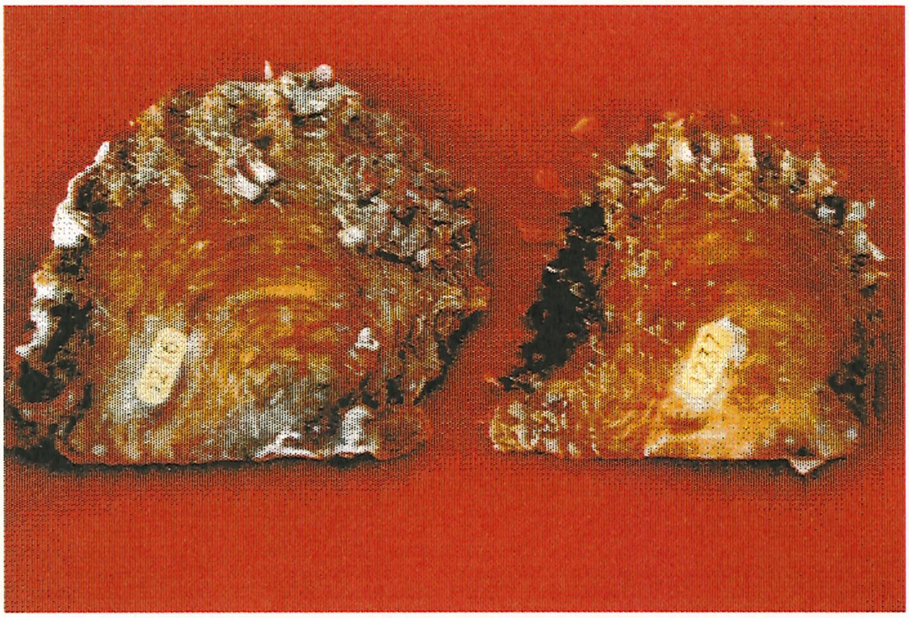


Fig. 4 Tagged Pearl Oysters

A. PVC tags attached with epoxy (white border) and cyano-acrylate glues.

B. Small pearl oysters with polyethylene tags attached with cyano-acrylate glue.



C. Recaptured culture-sized oysters - orange PVC tags attached with cyano-acrylate glue.

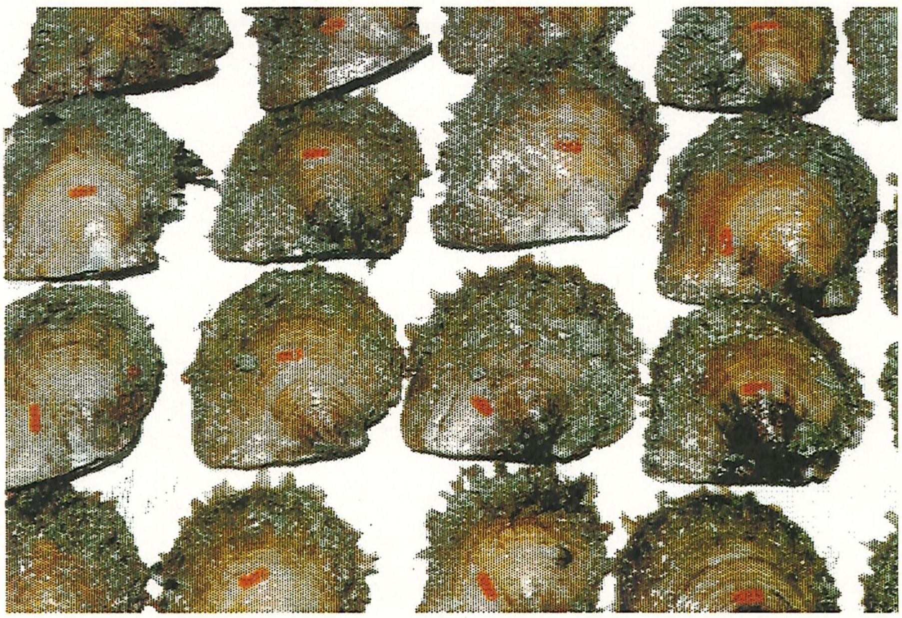


Fig. 5 Growth increment of tagged pearl oyster 1989-90, 1990-1992, 1989-1991.

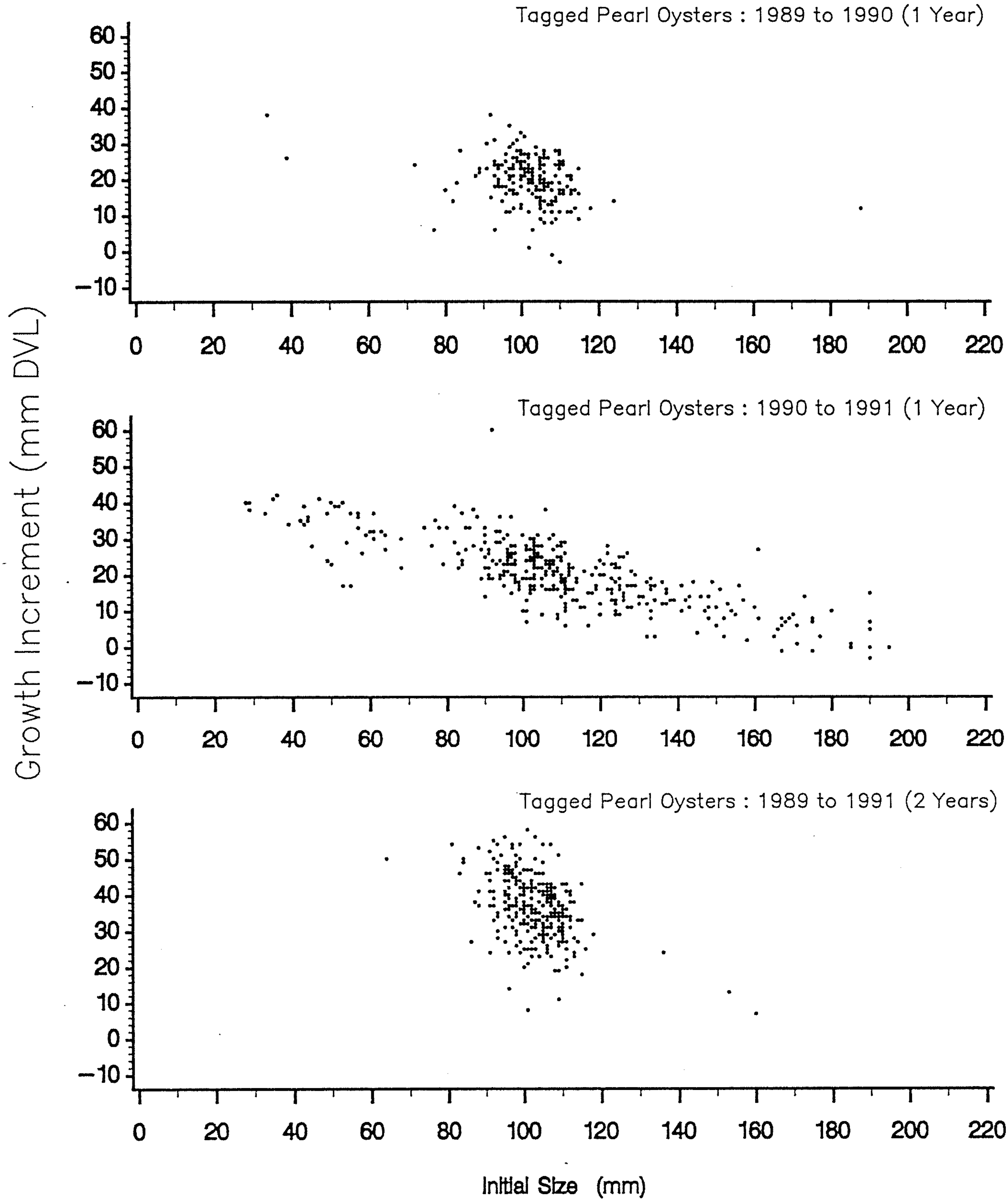


Fig. 6 Catch rate versus cumulative catch for the three grids with the highest catch rates.
a) 1990

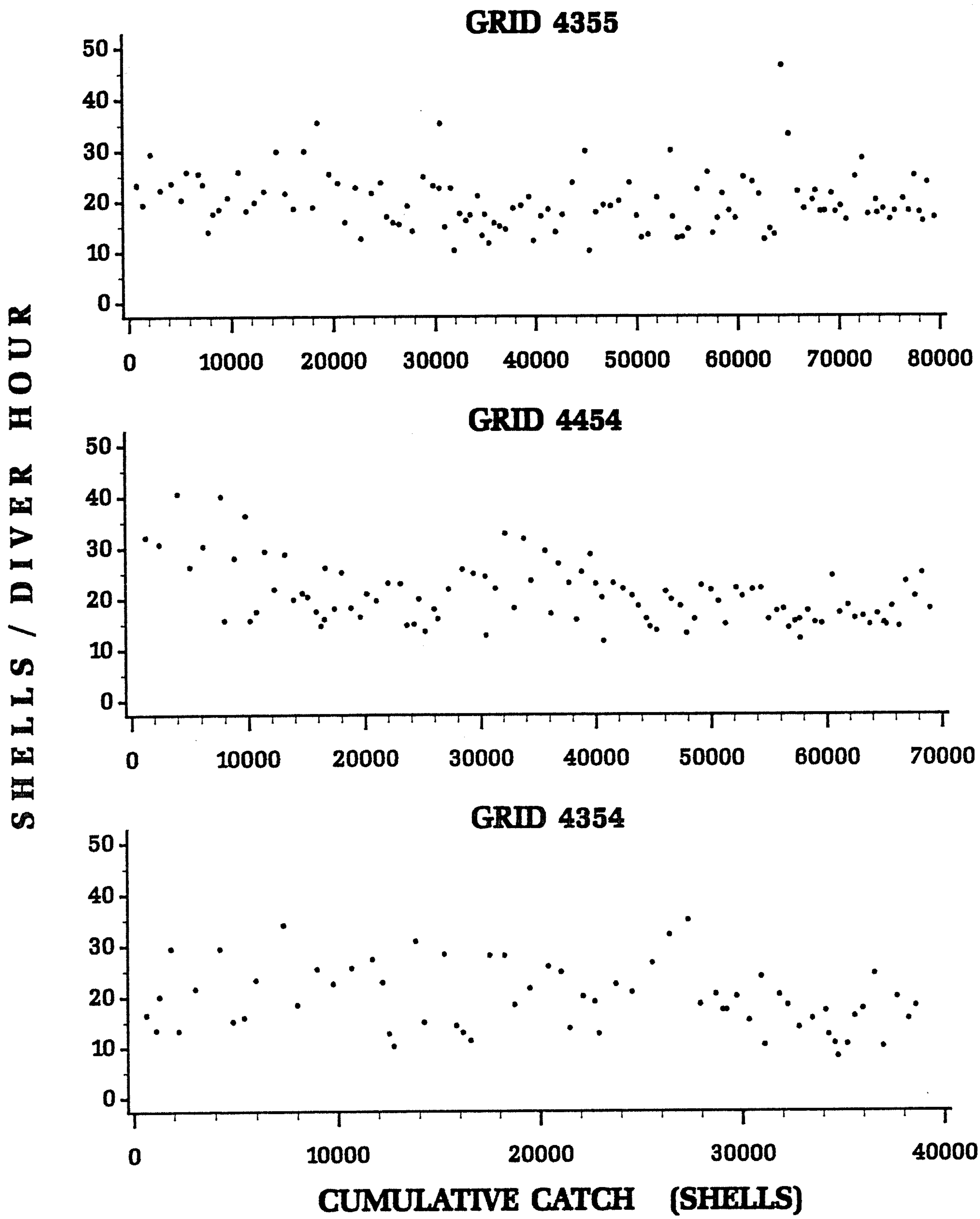


Fig. 6 Catch rate versus cumulative catch for the three grids with the highest catch rates.
b) 1991

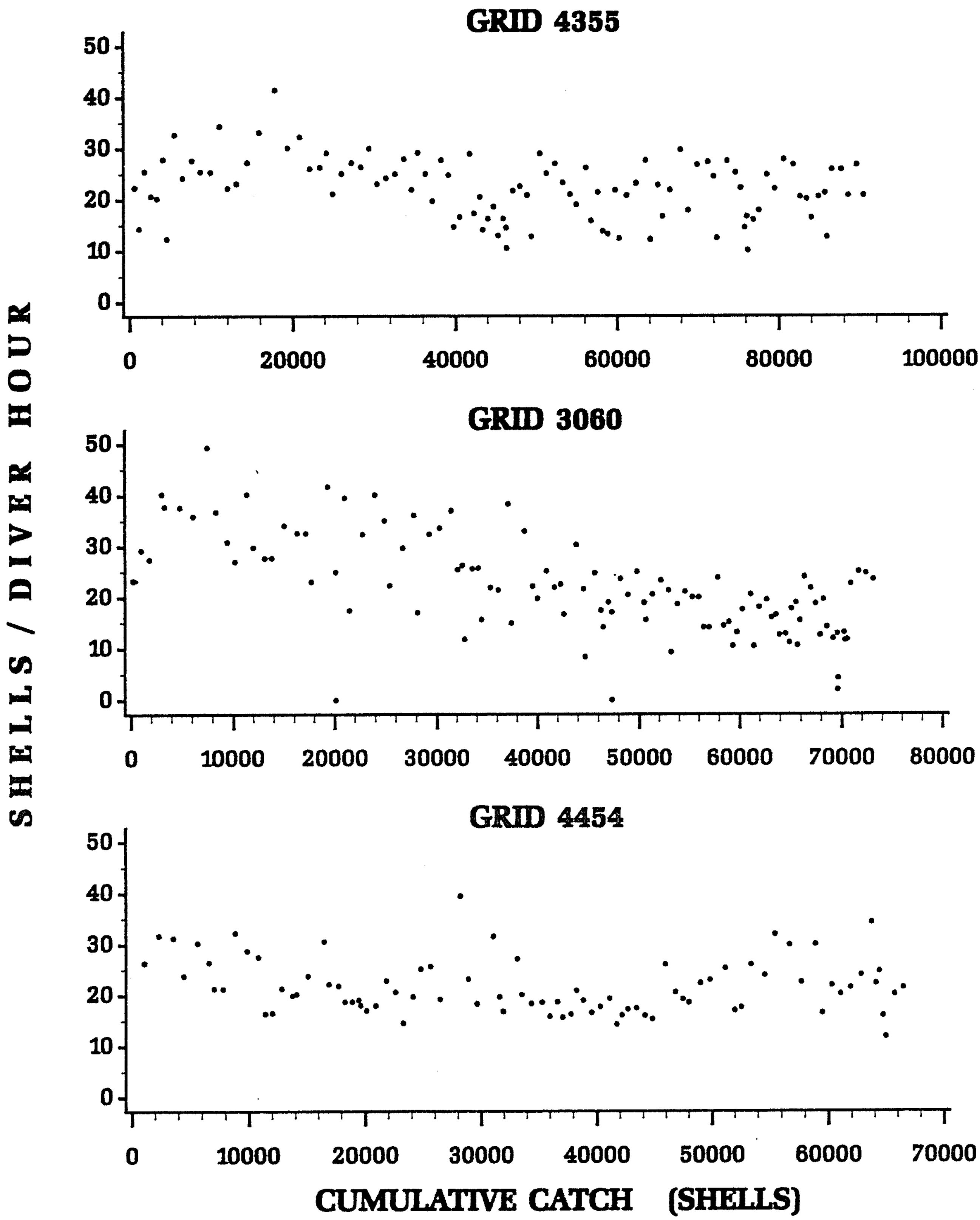


Fig. 6 Catch rate versus cumulative catch for the three grids with the highest catch rates.
c) 1992

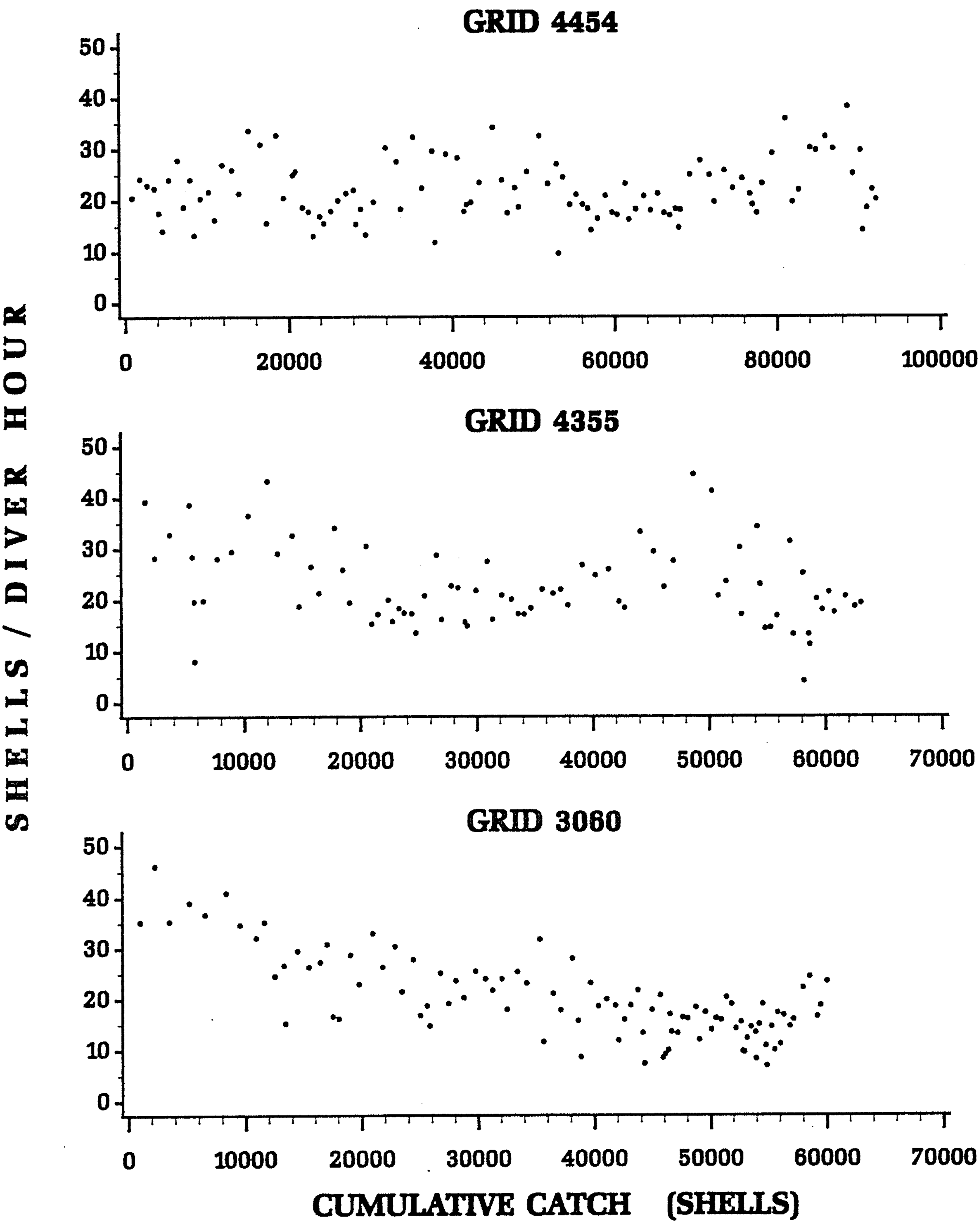
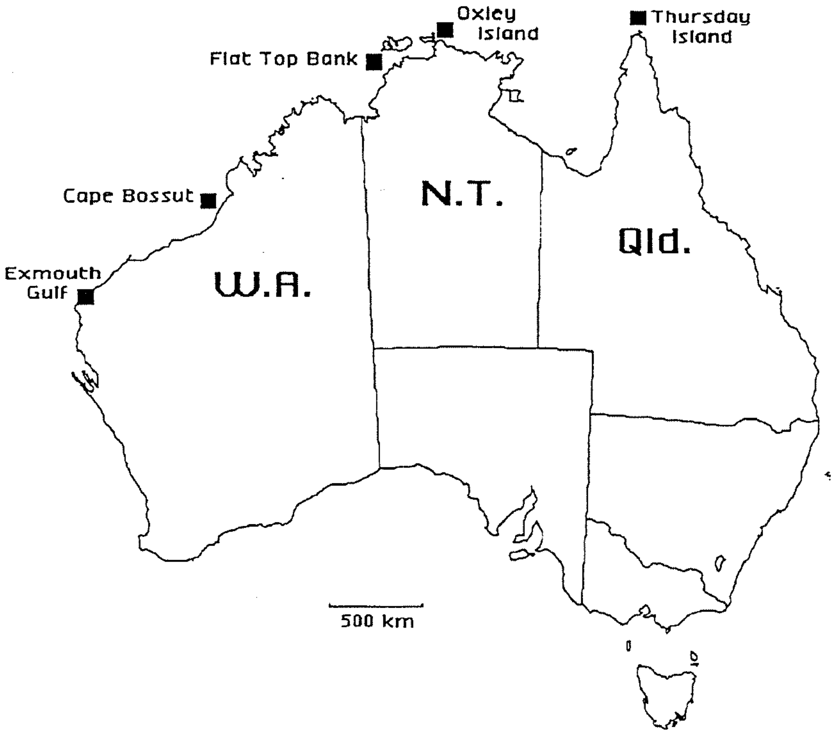
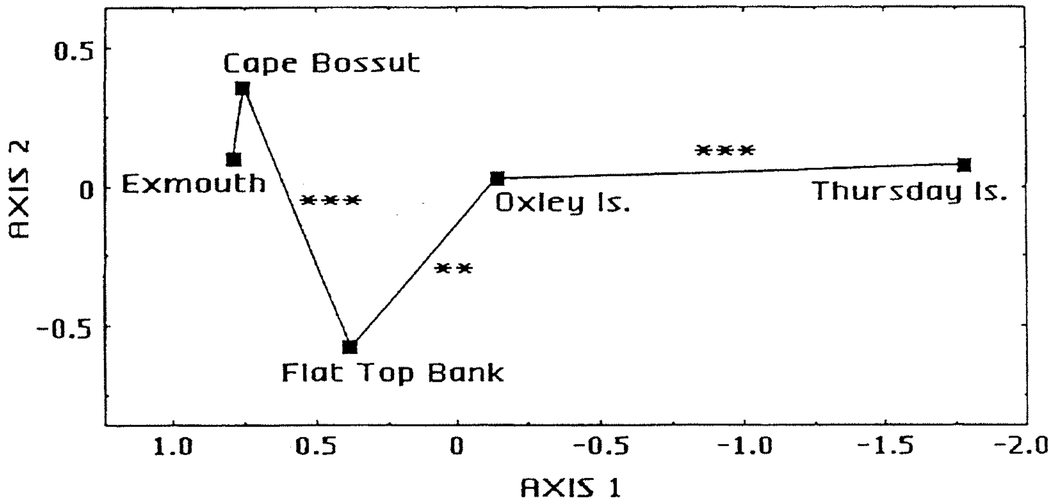


Fig. 7 Sampling Sites for Genetic Studies



(From Johnson and Joll 1993)

Fig. 8 Results of Genetic Studies of Australian Pearl Oyster Stocks



Significance of genetic differences between populations

*	$P < 0.05$
**	$P < 0.01$
***	$P < 0.001$

(From Johnson and Joll 1993)

Fig. 9a Spat collector sites - Eighty Mile Beach

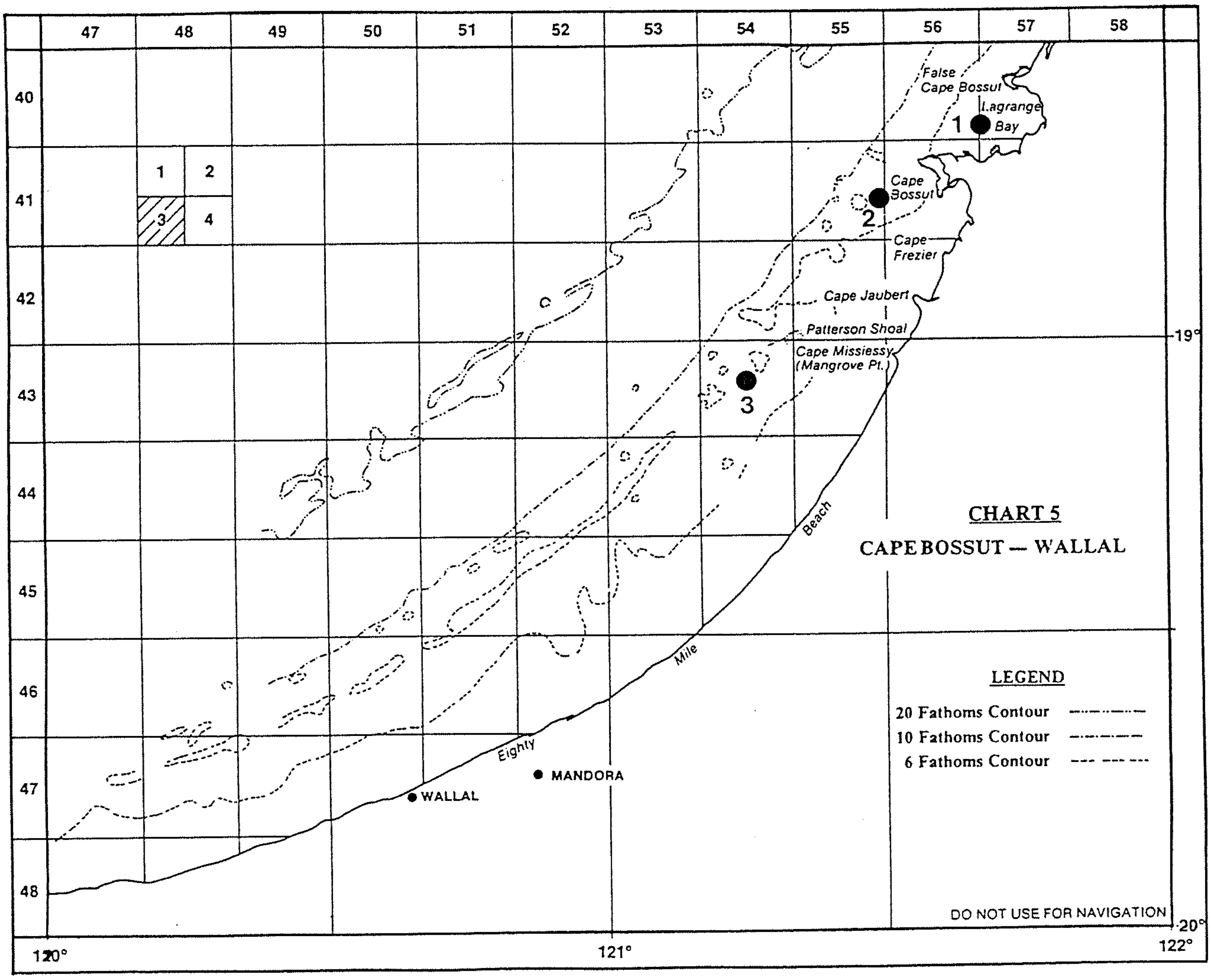


Fig. 9b Spat Collector Sites - Exmouth Gulf

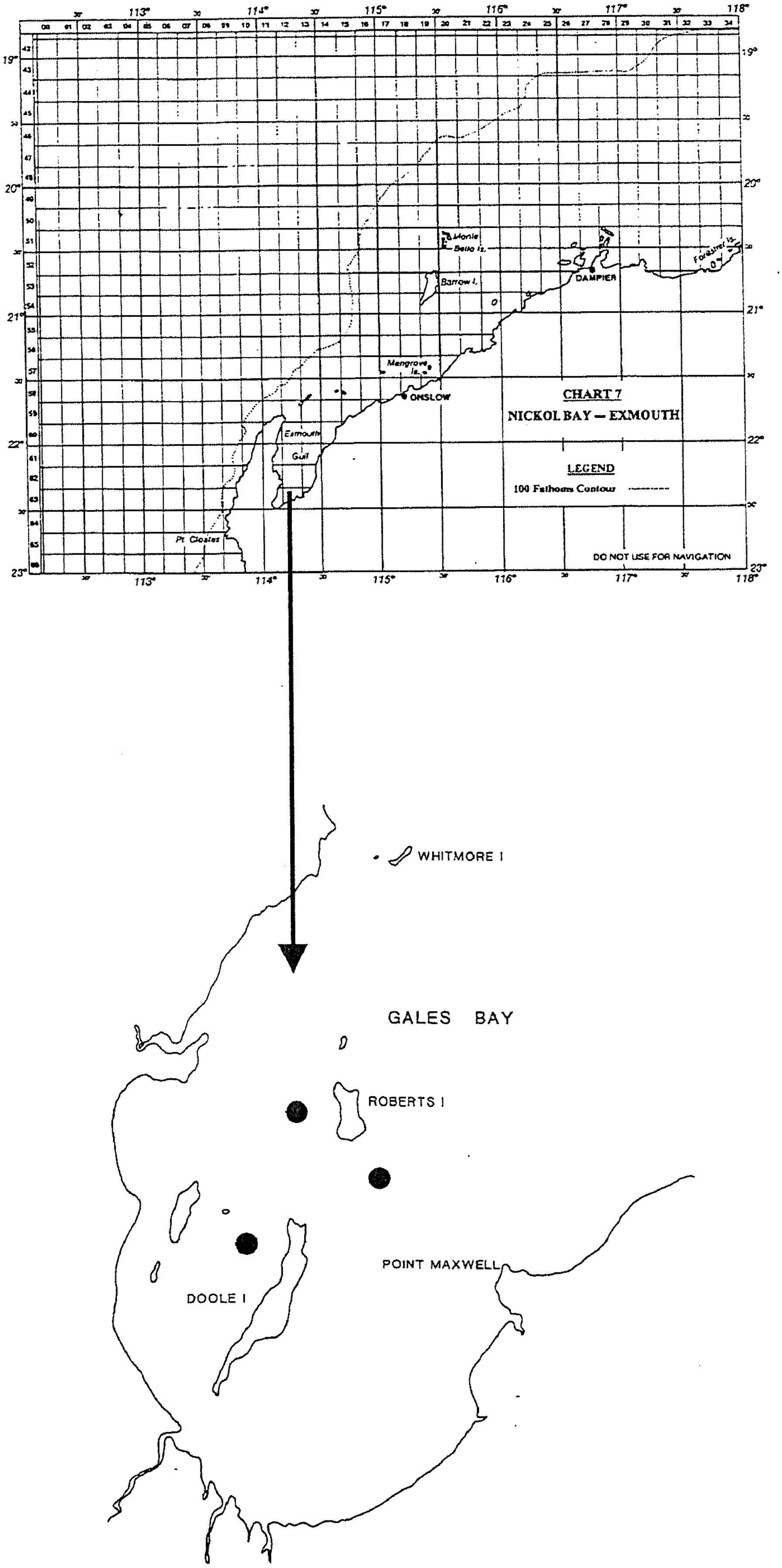


Fig. 10a Spat Collectors Used at 80 Mile Beach 1989-90

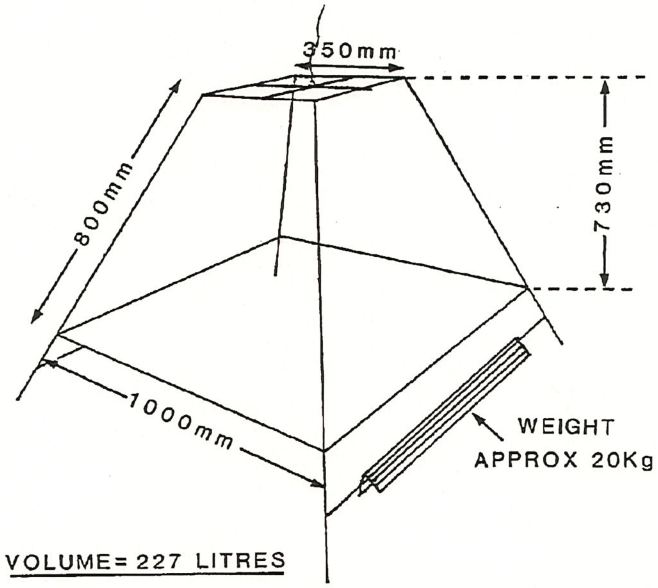
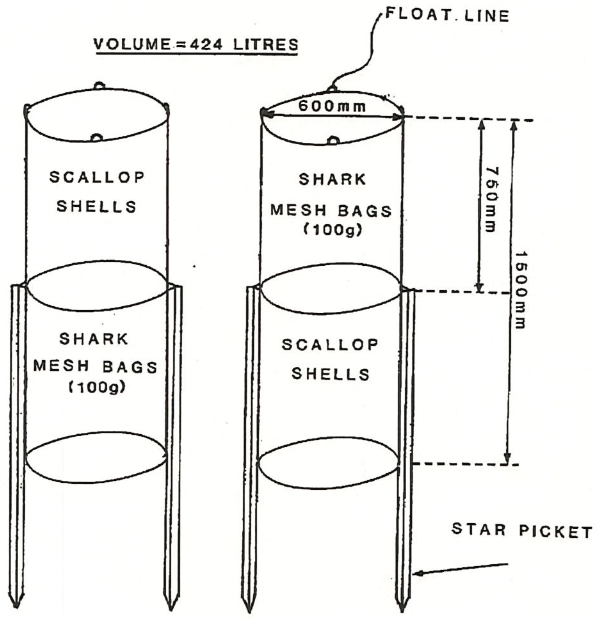


Fig. 10b. Spat Collectors Used in Exmouth Gulf 1989-90



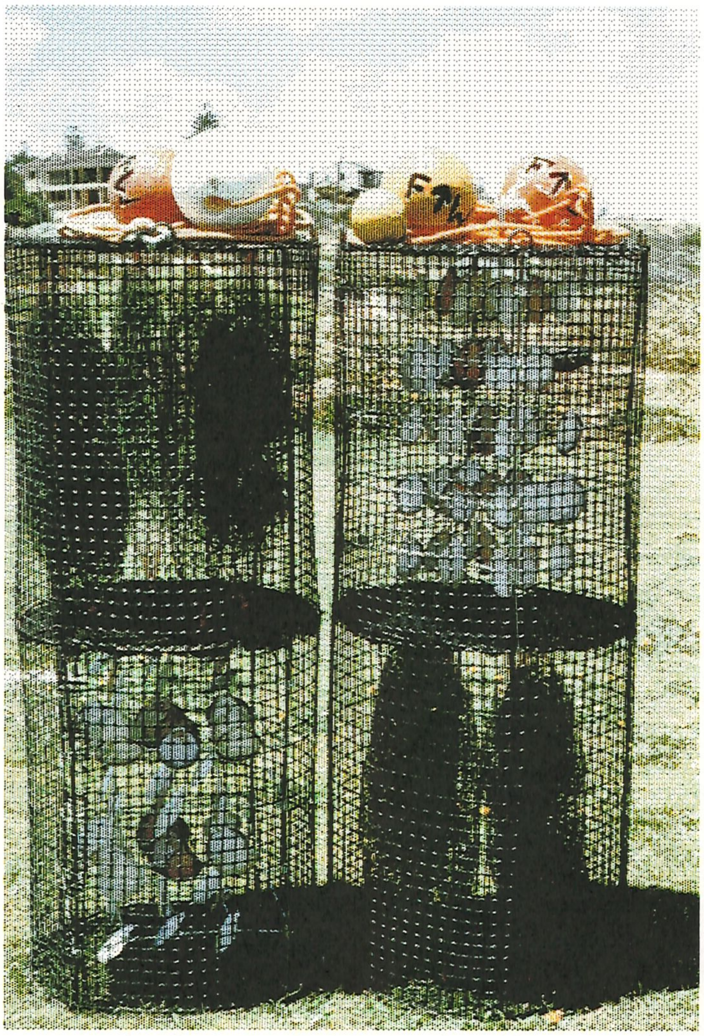


Fig. 10c Spat Collector Used at 80 Mile Beach 1990-91

- Substrates Used and Internal Arrangement

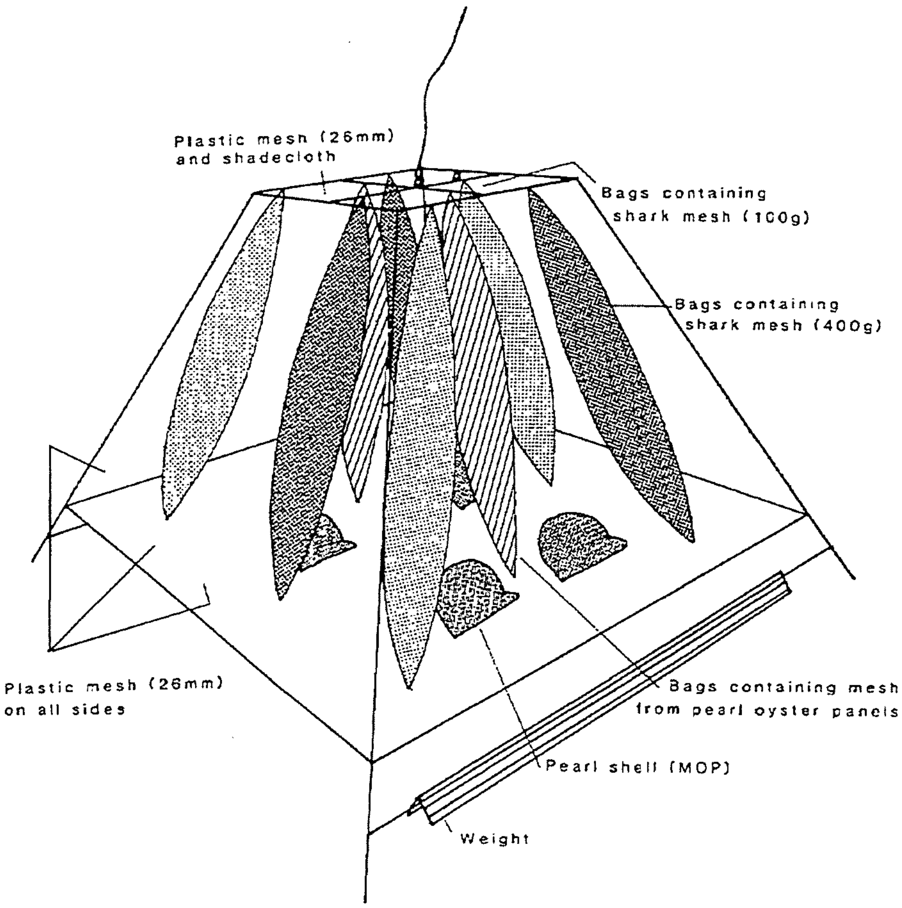
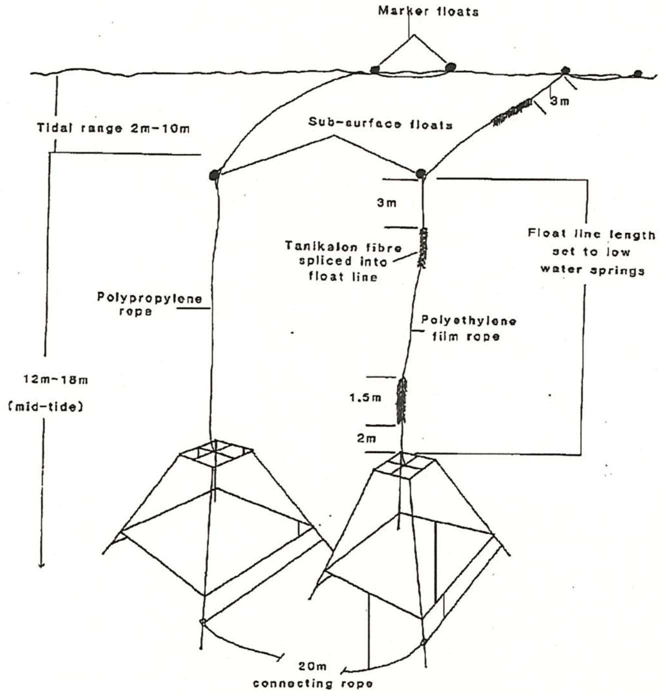


Fig. 10d. Spat Collector Used at 80 Mile Beach 1990-91

i). General layout



ii). Tanikalon fibre woven into polyethylene film rope

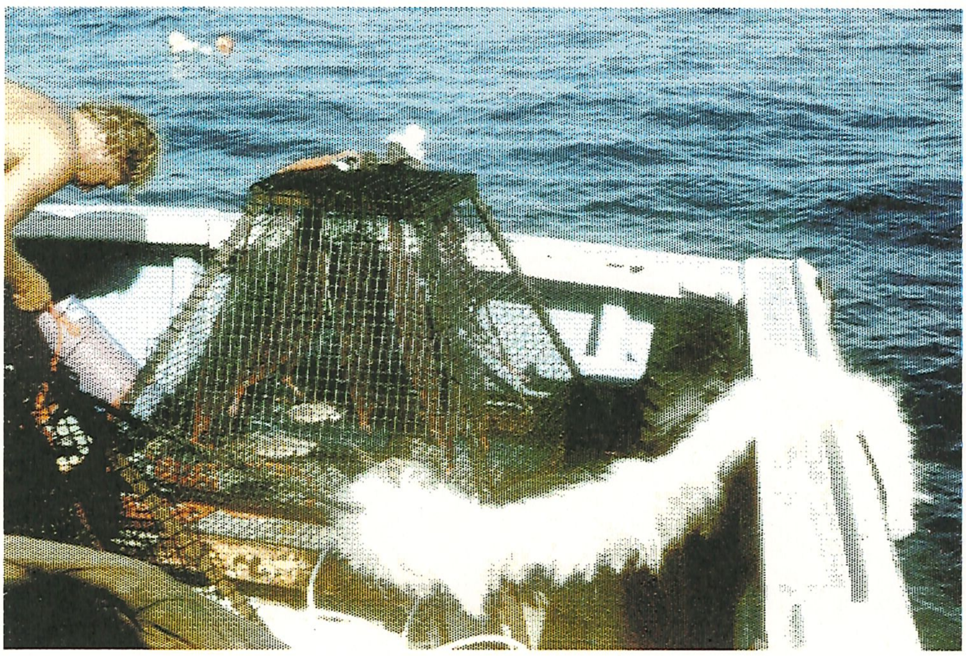


Fig. 11 Size frequency of spat from Eighty Mile Beach collectors.

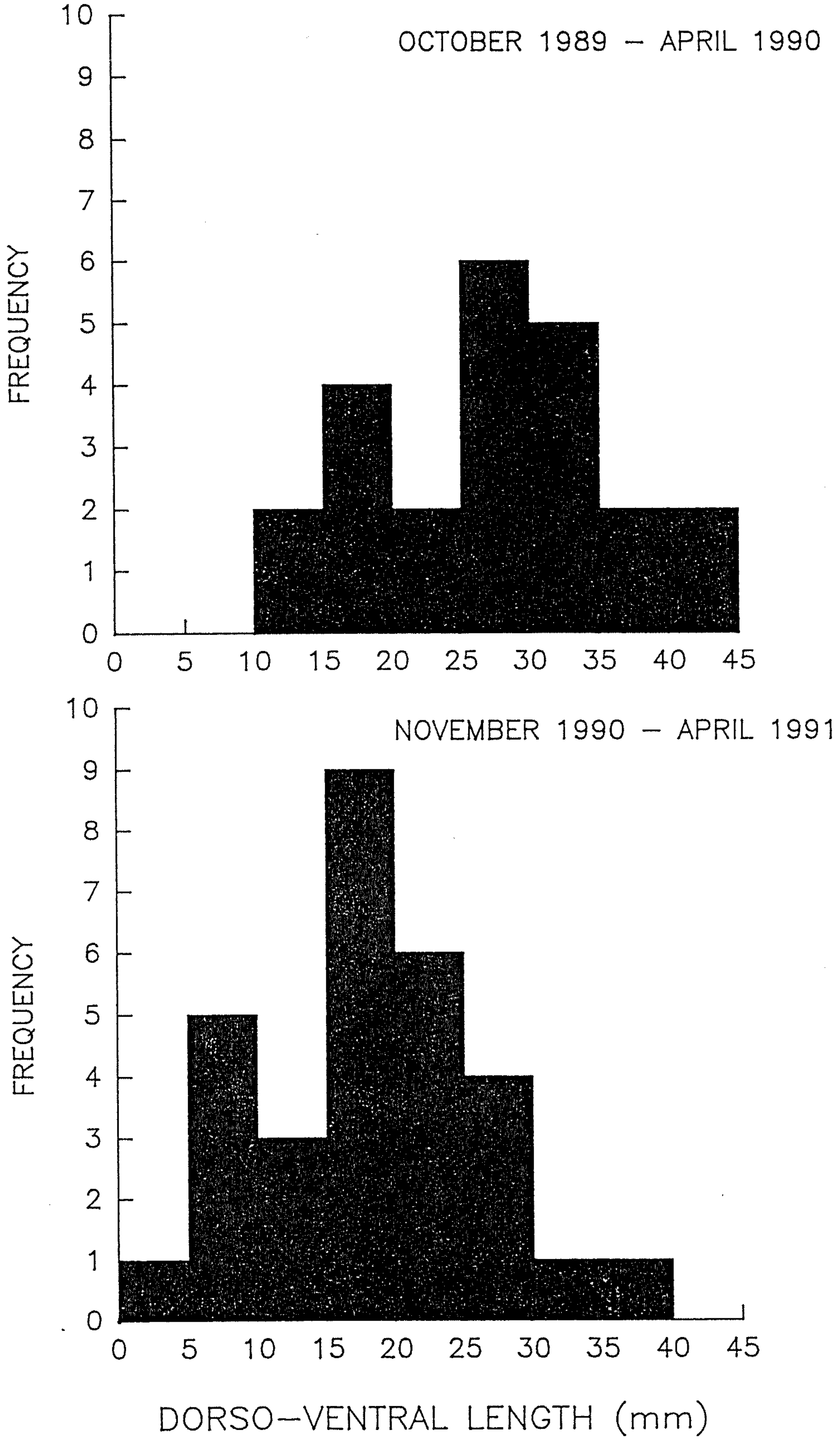


Fig. 12 Piggy-back Spat Attached to Culture-Size Shell

Fig. 13 Piggy-back spat size frequency distribution.

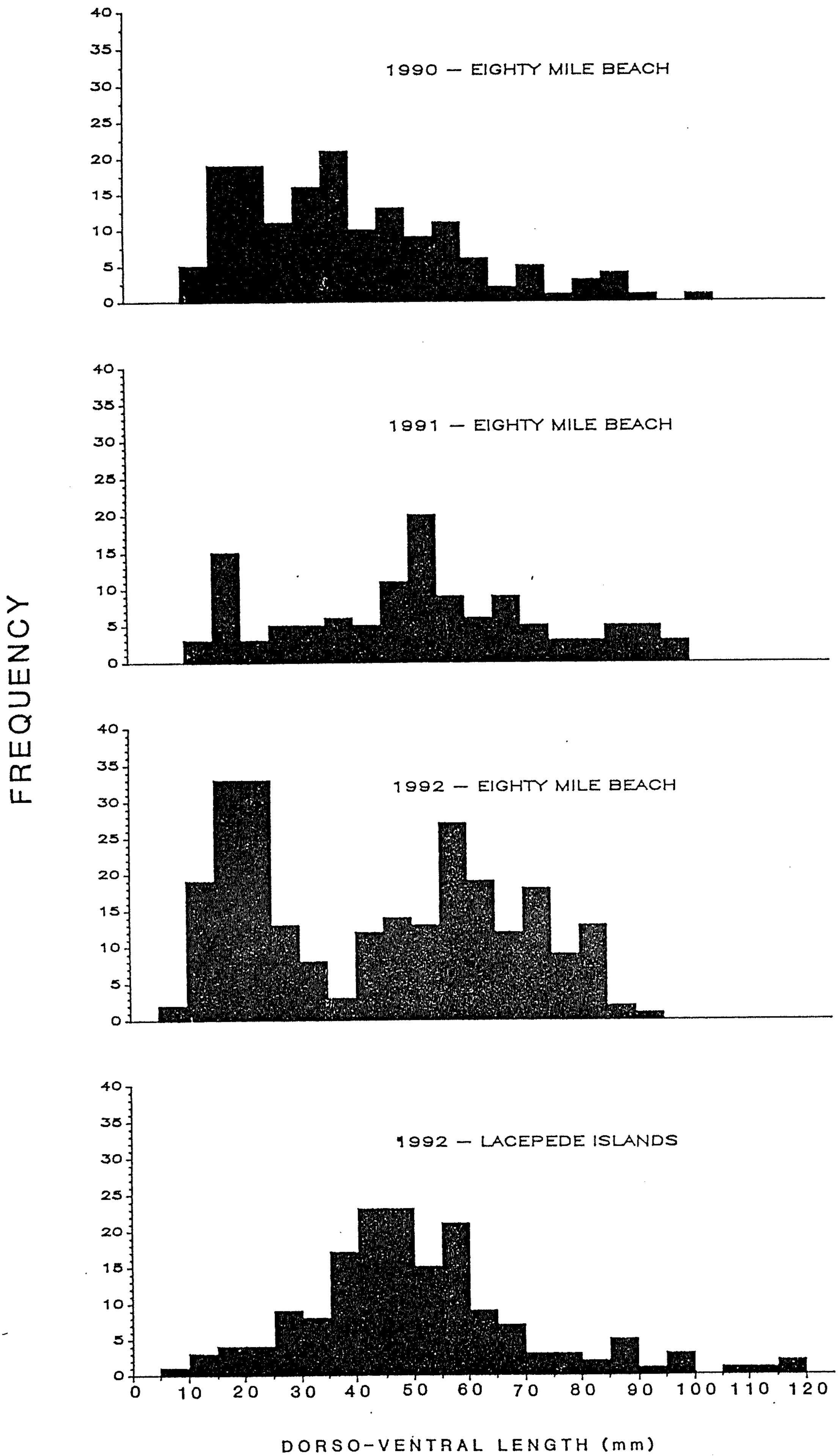
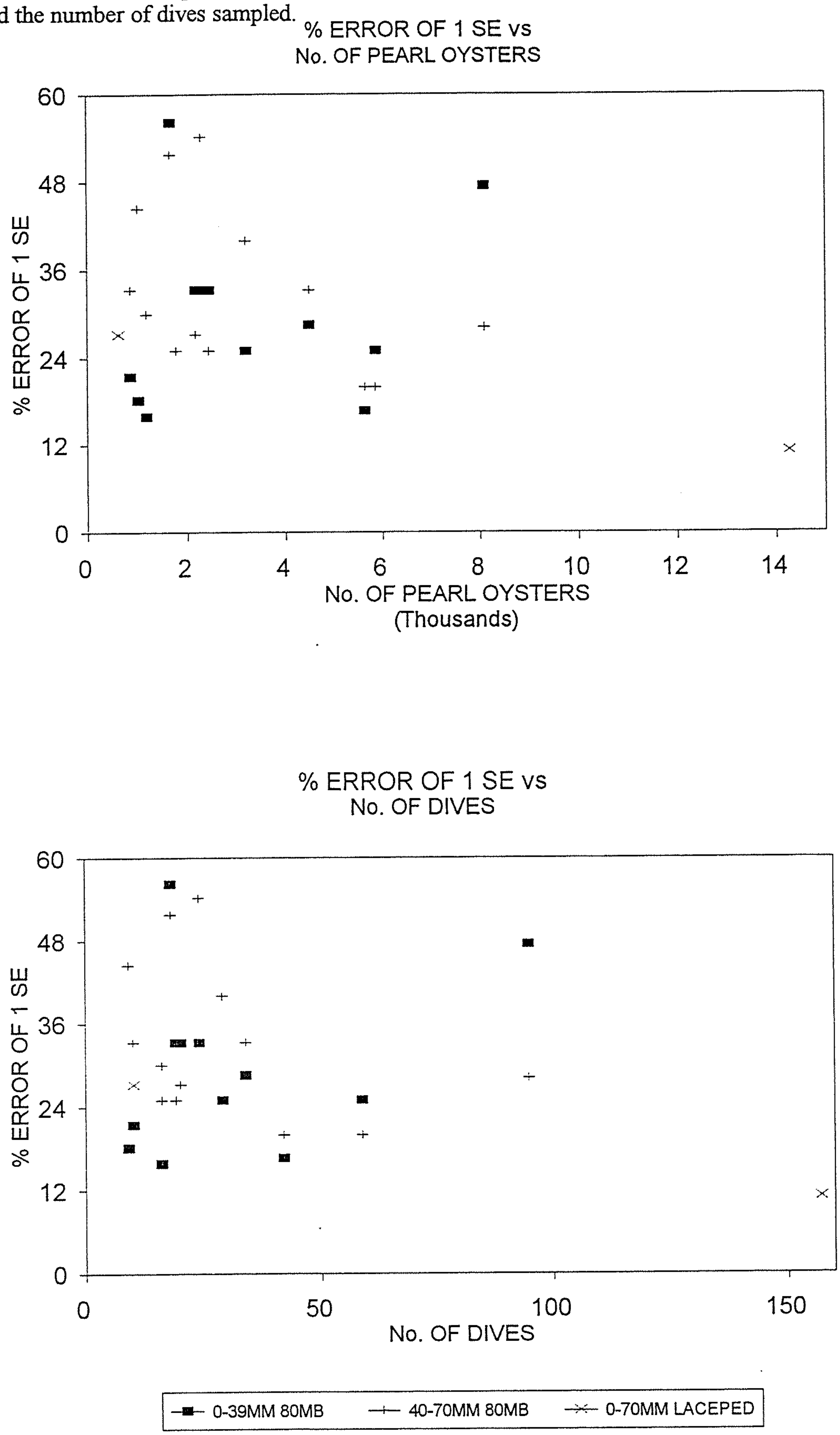


Fig. 14 Variation in the percentage represented by 1 standard error of the mean spat rate on culture-sized pearl oysters, versus the number of pearl oysters and the number of dives sampled.



Form P3

PEARL OYSTER FISHING – DAILY LOG SHEET

1332

Date: ____________________

Trip no. ____________________

Heap no. ____________________ *(Research Division only)*

Diver's no. and name

1 ____________ 5 ____________ 9 ____________
2 ____________ 6 ____________ 10 ____________
3 ____________ 7 ____________ 11 ____________
4 ____________ 8 ____________ 12 ____________

Boat name: ____________________

LPB no. ____________________

Grid Reference	Patch name/no.	Dive no.	Depth (m)	Water temp	Dive time			Pearl oysters taken by diver number												Total culture pearl oysters	Total MOP	Comments
				Surface / Bottom	Start	End	Mins	1	2	3	4	5	6	7	8	9	10	11	12			
		1																				
		2																				
		3																				
		4																				
		5																				
		6																				
		7																				
		8																				
		9																				
		10																				
		11																				
		12																				
		13																				
		14																				
		15																				
		16																				
Mean depth				Total dive time																		TOTAL TODAY / Est. total wt MOP ______ kg

DAILY TAG RECORD

Held on boat (Y/N)	Panel size	Dump No.	Tag serial No.	No. tags used	No. pearl oysters
				Total	

QUOTA RECORD

Total pearl oysters taken today	
Total pearl oysters taken this trip	
Total pearl oysters taken this year	

Master's declaration

I, ______________________________

the master of this boat certify that:

(1) The information contained herein is true and correct;

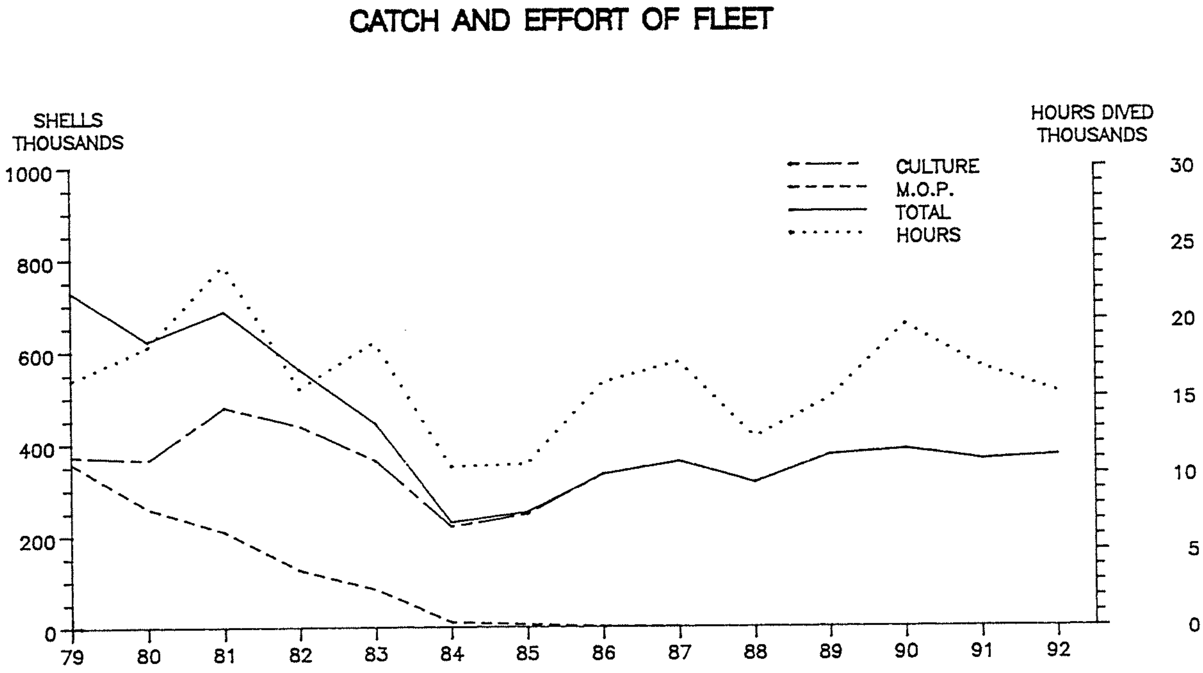
(2) all pearling activities undertaken on or from this boat have been in accordance with the Pearling Act and Regulations.

Signature ____________________ Date ____________

WHITE COPY – To Fisheries Department, YELLOW COPY – Owner's copy, GREEN COPY – Retain in log book

Fig. 15 Pearl oyster log book page.

Fig. 16 Time series of catch, effort and catch per unit effort of the pearl oyster fishing fleet.
a) Zone 2, 1979-1992.



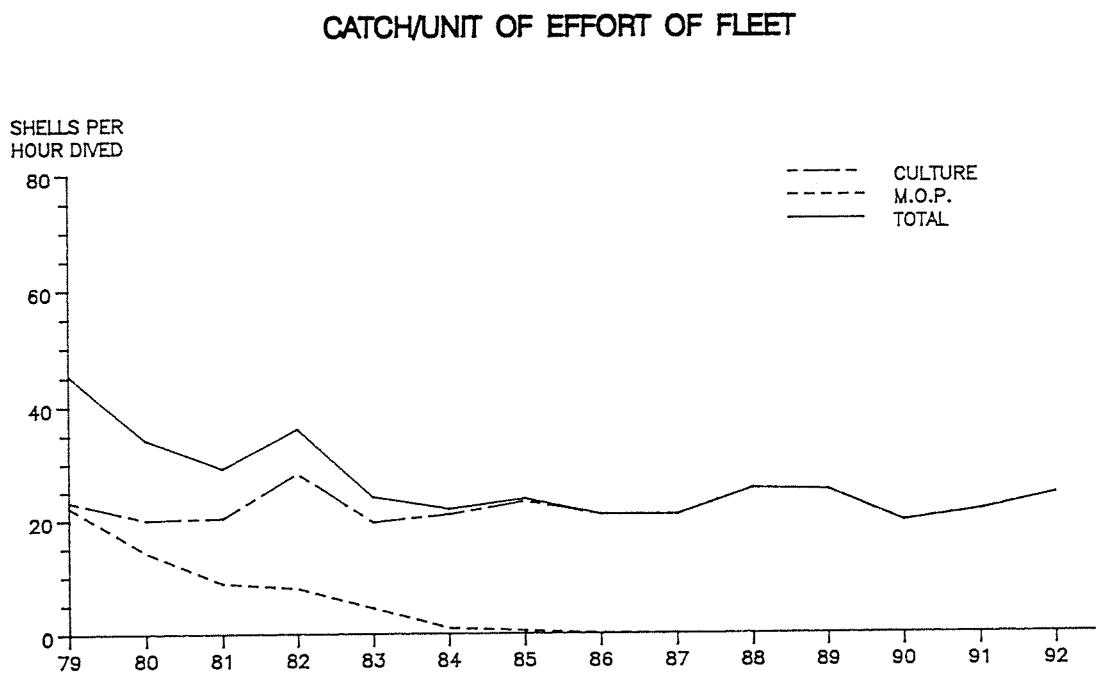
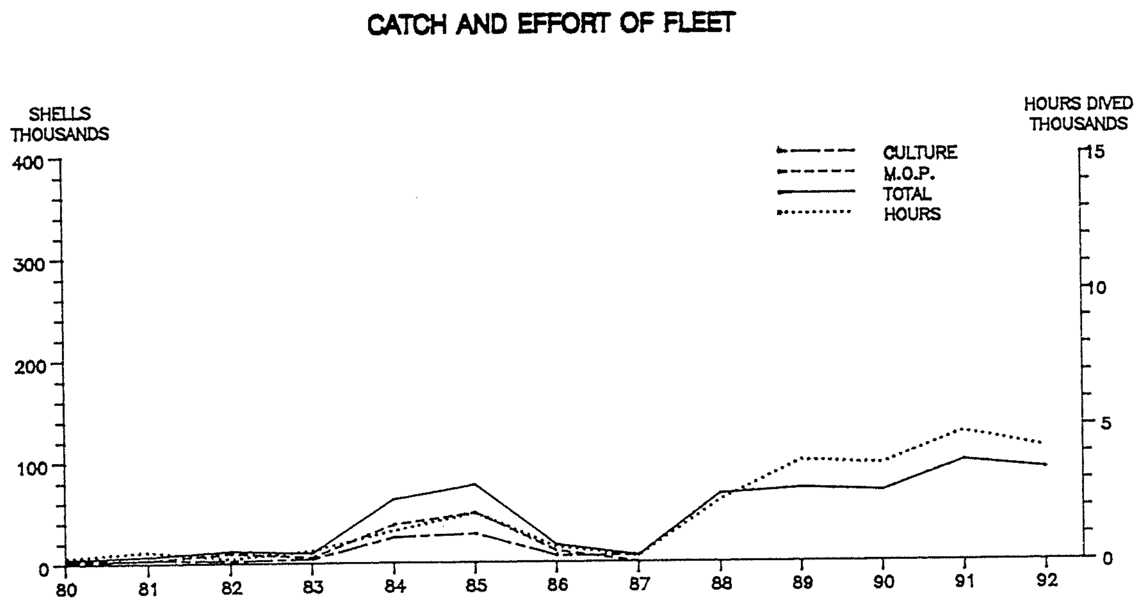
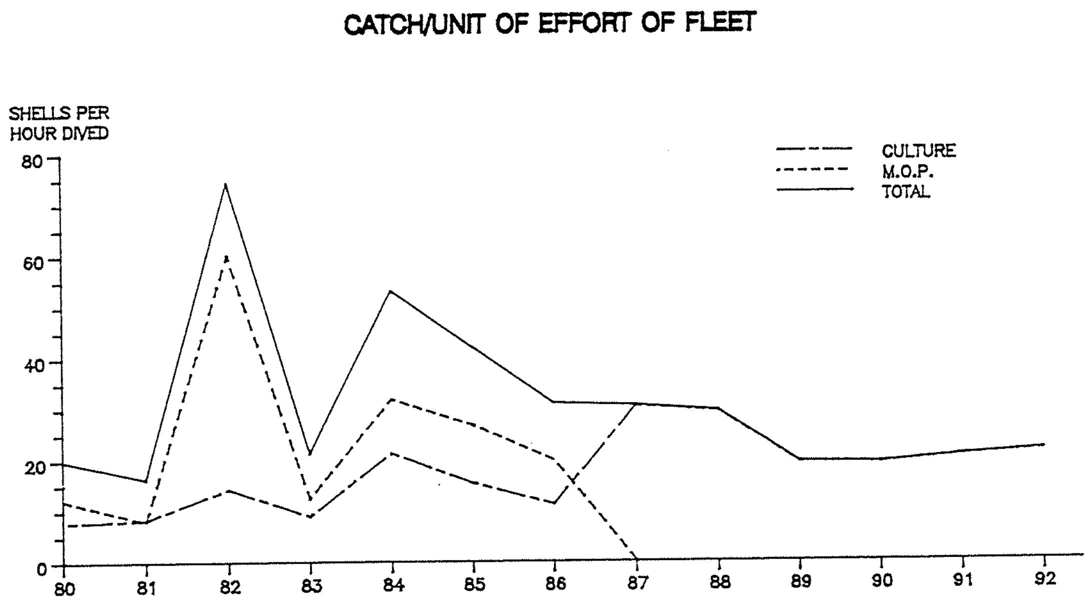


Fig. 16 Time series of catch, effort and catch per unit effort of the pearl oyster fishing fleet.
b) Zone 3, 1979-1992.





Appendix 1

EXPLORATORY SURVEY OF PEARL OYSTER STOCKS IN THE NORTHERN KIMBERLEY AREA OF WESTERN AUSTRALIA, JULY 1989 - FEBRUARY 1990.

L. M. JOLL

Fisheries Research Branch

Western Australian Fisheries Department

August 1990

INTRODUCTION

The report of the Pearling Industry Review Committee (Malone et al. 1988) recommended that the waters off the northern Kimberley coast (125° to 129°E) be identified as a development zone, with the harvesting of oysters by existing or new licencees requiring the special permission of the managing authority. This recommendation was adopted by the Commonwealth Minister for Primary Industry and Energy and the Western Australian Minister for Fisheries, with the area being re-defined as 125°12' to 129°E.

The strategy for development of the zone was to establish a two-phase approach, with the first phase involving test-fishing and the second phase, the granting of pearl quota for the Kimberley area, being dependant on decisions taken following analysis of the results of the test fishing. An advertisement for applications to participate in phase one of the development strategy was lodged in national and state newspapers on 4 February 1989. Fourteen applications were received and the applicants interviewed in either Perth or Broome in May 1989.

The interview panel was satisfied that, for the most part, all applicants fulfilled the necessary criteria governing the selection of participants in the test fishing programme. However, all applicants were informed that an authority granted to participate in phase one would not confer any special benefits in relation to decisions made on the allocation of any future authorities to fish pearl shell.

The applicants were advised by letter on 6 June 1989 that their application to participate in the test fishing had been approved and that they could commence fishing as soon as the necessary formalities relating to the acknowledgement of the conditions had been completed and authorities to fish had been issued. The completion date for the test fishing programme was set at 28 February 1990.

GUIDELINES

Guidelines for the test fishing allowed for up to 7500 oysters to be retained for use as live oysters for pearl culture or as mother-of-pearl (MOP) shell. In addition, existing pearling licence holders were given a special dispensation to purchase pearl oysters caught in the test fishing programme in addition to their authorised quotas.

The main focus of interest of most of the applicants was in the Holothuria Bank and Admiralty Gulf areas. In order to encourage a wider spatial spread of data gathering activity the participants were limited to fishing for 4 neaps in the Admiralty Gulf - Holothuria Bank area (i.e. between 125°36'E and 126°30'E), with no more than 2 neaps spent in the Admiralty Gulf area (i.e. south of a line connecting Cape Voltaire and Gibson Pt.) (Fig. 1).

Participants were required to provide details of their fishing results and were requested to also include any ancillary data on the nature of the sea-bed and fishing conditions. Data was to be recorded using the standard pearl fishing log books.

RESULTS

Of the fourteen original applicants only six eventually participated in the test fishing, although two participants combined for the operations of one vessel, with the result that only five vessels operated in the area. The nature of the data gathered varied between these vessels, with some providing detailed latitudes and longitudes for drifts and spot dives while others only provided a more general position relating to the 10mile x 10mile grid of the pearl fishing log book or comments related to the grid.

The areas for which data was gathered by the vessels involved in the test fishing are indicated in Figures 2 - 6. Each survey location is numbered, with survey items relating to a specified location being marked with a solid circle at the location, while items relating to a whole 10mile x 10mile block are marked with just the item number in the block. The items for each vessel are detailed in Tables 1 - 5. Where several drifts were conducted within a 10 mile x 10 mile block the survey data are condensed to show a mean catch per unit effort (CPUE - expressed as shells {MOP and culture} per diver hour) and the range of CPUE for all drifts in that block. The percentage of culture shell in the catch is indicated in the tables where MOP and culture were recorded separately.

CONCLUSIONS

The results indicate that there are some areas of potential pearl oyster grounds, although the only grounds which were subjected to rigorous fishing effort were those around the north end of Holothuria Banks (Baldwin Bank, Warn Rock, Penguin Shoal and Penguin Deeps). The results for Vessel 3 showed catch rates which could be considered commercially viable on culture-size shell alone (i.e. around 20 culture shell per diver hour). The only other vessel (Vessel 3) which expended high levels of fishing effort recorded catch rates which could only be considered commercial if the MOP catch was included in the commercial take. However, the presence of small areas of high abundance in the north Holothuria Banks area was noted by the skipper of Vessel 4 but serious fishing was prevented by strong tides and poor visibility.

Comments on the wormy nature and generally poor quality of MOP were made by the skipper of Vessel 4, although he noted that the young shell were of good quality. The operators of Vessel 1, however, considered that most of the MOP was of good quality and that the quality of the culture shell was very high.

The comments based on the echo sounder survey of Vessel 5 and the fishing results of the the other vessels outside the north Holothuria Banks area indicate that other areas of potential pearl oyster resources exist. However none seemed to exhibit the same potential as the north Holothuria Banks area. Furthermore, some of the comments indicated that diving conditions in areas nearer to the coast were generally not good - at least at the time that the vessels were in the area.

Based on the results from the north Holothuria Banks area there would appear to be a strong possibility of good pearl shell areas on Van Cloon Shoal (12°40'S 126°25'E) and possibly Favell Bank (12° 43'S, 126°10'E) and Gale Bank (12°37'S, 126°5'E). However, the lack of any suitable pearling bottom in the area of The Boxers (11°20'S, 128°30'E) reported by Vessel 1 must also be noted.

The data resulting from the survey indicate that areas of high pearl shell density, capable of supporting commercial catch rates, exist in the north Holothuria Banks area. However, the results do not provide a measure of the total fishable stock available on a sustained basis. Nevertheless, the area of good catch rates appears to be fairly small, so that the potential sustainable catch is unlikely to be large. The percentage of culture-sized shell in the catch of vessels 3 and 4 was similar to that recorded for "good" grounds in the area north-west of Broome in the "Flinders" survey (Penn and Dybdahl, 1988), suggesting a similar rate of recruitment in the two areas. The fishing strategies of Vessels 3 and 4 may, however, have differed from that of the "Flinders" survey, which would limit the value of this comparison.

FURTHER AVENUES

The data resulting from the survey does not provide an adequate basis for determining the appropriate commercial catch for the area. To provide an better basis for decisions it would be desirable to apply some additional commercial fishing effort in a manner which yields some further data. Some possible approaches are:

1. Active commercial fishing of culture sized shell in defined areas over a period of 2 - 3 years. Shell fished would be non-quota, so that the catch would not controlled by any anticipated outcome. However, the area would need to be properly defined with respect to the available effort so that the catch and catch rates represented an adequate level of exploitation of the stock. Also, given that the culture size group probably contains several year classes, some further data on the size ranges taken would be required to properly assess the results. The data obtained would provide a means of estimating the recruitment into the population which could then be used as guide in setting future catches for the area.

2. A gradual increase in commercial fishing effort for culture shell over time. This would involve initially releasing a small amount of quota which would then be increased gradually over time and the response in terms of catch per unit effort monitored. Again, the area of application of the fishing effort would need to be properly defined so that changes in the stock level were not masked by moving the fishing activity to new areas. Increases in quota would have to be understood by all parties to be experimental and subject to withdrawal in the event that the population showed signs of undesirable levels of fishing pressure.

3. Open the whole area to fishing for culture shell by one or more operators (new entrants or existing quota holders) on a temporary basis (3 to 5 years). A decision on the usefulness of the area for commercial operations would be made at the end of the temporary period by an economic assessment of the operators. Initial quota allocations to entrants would be made on the basis of potential economic viability rather than on biological criteria.

Table 1 VESSEL 1

ITEM	GRID	LAT (S)	LONG (E)	DEPTH (m)	TDT	CPUE	% CULT.	VIZ. (m)	BOTTOM
1	1380	14° 1.9'	125°39.9'	21	40	1.5	0	5	Reef, light garden
2	1381	14° 2.0'	125°41.0'	18	30	10.0	20.0	5	"
3	1381	14° 2.9'	125°42.2'	16	40	30.0	15.0	5	"
4	1381	14° 4.6'	125°46.1'	15	40	7.5	20.0	5	"
5	1381	14° 6.9'	125°46.2'	14	30	6.0	33.3	3	"
6	1381	14° 5.8'	125°46.7'	13	20	0	0	2	"
7	1381	14° 8.8'	125°48.9'	13	30	6.0	0	2	Reef,Sand, light garden
8	1382	14° 5.0'	125°50.2'	17	40	7.5	0	3	"
9	1382	14° 4.6'	125°51.0'	11	20	0	0	2	"
10	1382	14° 2.2'	125°51.2'	11	10	0	0	2	"
11	1382	14° 3.5'	125°51.6'	19	10	30.0	0	3	"
12	1382	14° 0.3'	125°50.6'	15	10	0	0	3	"
13	1281	13°55.4'	125°47.9'	15	50	2.4	50	3	Sand, light garden
14	1182	13°48.8'	125°50.1'	17	10	12.0	0	3	"
15	1182	13°48.7'	125°50.7'	15	10	0	0	3	"
16	1181	13°43.2'	125°49.8'	22	10	0	0	3	"
17	1082	13°36.5'	125°51.2'	22	10	0	0	2	Reef, no growth
18	1082	13°35.2'	125°53.2'	20	10	0	0	2	"
19	1082	13°30.2'	125°53.6'	19	10	0	0	2	"
22	982	13°23.8'	125°53.6'	22	10	0	0	2	Sand
23	983	13°25.0'	126° 1.4'	27	10	0	0	2	Reef,Sand light garden
24	983	13°28.4'	126° 6.0'	27	10	6.0	100.0	2	Sand, light garden

Table 1 (cont.)

ITEM	GRID	LAT (S)	LONG (E)	DEPTH (m)	TDT	CPUE	% CULT.	VIZ. (m)	BOTTOM
25	983	13°30.2'	126° 6.4'	23	10	0	0	2	"
26	1083	13°31.4'	126° 7.1'	23	10	6.0	100.0	2	"
27	1083	13°33.5'	126° 6.8'	19	10	6.0	100.0	2	"
30	1084	13°38.3'	126°11.1'	18	-	-	-	0	Unknown
31	1184	13°42.0'	126°10.7'	23	-	-	-	0	Unknown
32	1183	13°45.4'	126° 7.3'	18	10	0	0	1	Sand, light garden
33	1283	13°52.8'	126° 4.3'	25	10	0	0	1	"
34	1284	13°51.5'	126°16.6'	25	10	0	0	2	"
35	1284	13°51.9'	126°17.1'	20	10	0	0	2	"
36	1284	13°52.6'	126°17.0'	18	40	16.7	18.0	3	Reef, heavy garden
37	1284	13°52.5'	126°17.4'	18	80	18.0	25.0	3	"
38	1284	13°53.1'	126°16.8'	15	10	0	0	3	Sand
39	1284	13°51.5'	126°17.7'	15	10	0	0	3	"
40	1284	13°50.6'	126°17.2'	27	10	6.0	0	2	Sand, light garden
41	1284	13°50.7'	126°17.8'	14	10	12.0	0	2	"
42	1480	14°16.2'	125°34.1'	26	25	0	0	4	Sand, medium garden
43	1480	14°16.1'	125°33.6'	26	15	0	0	4	"
44	1480	14°14.7'	125°34.5'	28	10	0	0	4	"
45	1582	14°22.4'	125°52.9'	28	10	0	0	5	Mud
46	1582	14°21.7'	125°53.2'	34	10	0	0	1	Mud, Patches light garden
47	1582	14°21.6'	125°51.8'	25	10	0	0	0	Mud
48	1482	14°19.1'	125°51.2'	32	10	0	0	0	Mud
49	1284	13°58.0'	126°15.6'	17	10	0	0	5	Mud

Table 1 (cont.)

ITEM	GRID	LAT (S)	LONG (E)	DEPTH (m)	TDT	CPUE	% CULT.	VIZ. (m)	BOTTOM
50	1286	13°51.0'	126°33.7'	15	10	0	0	1	Sand, light garden
51	1286	13°57.2'	126°37.8'	22	10	0	0	2	Mud
52	1386	14°4.6'	126°33.7'	14	10	0	0	2	Mud
53	1187	13°45.6'	126°.41.8'	12	10	0	0	1	Mud
54	683	12°51.2'	126°8.0	26	60	28.0	28.6	10	Sand, heavy garden
55	683	12°50.9'	126°8.5'	27	60	33.0	30.3	10	"
56	683	12°50.5'	126°8.6'	25	10	18.0	0	10	"
57	683	12°50.4'	126°8.4'	25	60	42.0	33.3	10	"

Also 3 dives at Boxer Shoals (11°20'S,128°30'E): No suitable pearl bottom.

Table 2 VESSEL 2

ITEM	GRID	TDT (mins)	MEAN CPUE	CPUE RANGE	DEPTH (m)
1	0981	20	0	-	24
2	1081	98	1.2	3.0 - 0	18 - 22
3	1082	10	0	-	15
4	1181	152	2.4	9.0 - 0	15 - 20
5	1283	40	6.0	9.0 - 0	12 - 16
6	1380	120	2.0	3.0 - 1.0	20
7	1381	651	4.0	24.0 - 0	13 - 20
8	1382	145	2.5	4.0 - 0	17
9	1481	40	3.0	-	22

Table 3 VESSEL 3

ITEM	GRID	LAT (S)	LONG (E)	TDT (mins)	MEAN CPUE	CPUE RANGE	% CULT.	DEPTH (m)
	0584	12°49'	126°11'	780	70.0	102.7 - 21.3	30.3	30
2	0583	12°45'	126°10'	765	65.1	78.0 - 38.0	35.4	30 - 31
3	0783	13°07'	126°07'	1283	64.1	107.2 - 0	29.1	30
4	0982	13°25'	125°50'	1950	70.3	105.3 - 0	24.7	30

(+ 4 *Pinctada margaritifera*)

Table 4 VESSEL 4

ITEM	GRID	TDT (mins)	MEAN CPUE	CPUE RANGE	% CULT.	DEPTH (m)
1	1283	1208	6.5	16.0 - 3.8	49.1	22 - 27
2	0684	3874	16.3	36.6 - 6.1	45.6	24 - 33
3	0683	5306	14.2	30.8 - 4.4	37.1	23 - 32
4	0683	Small areas near N.W. edge of Baldwin Bank show high concentrations.				
5	0782 0783	Good bottom in Penguin Shoal and Warn Rock area, but tides very strong and visibility poor.				

Table 5 VESSEL 5

ITEM	GRID	COMMENT
1	1478	Between Walker I. and E. Montalivet I. - all hard coral 20 - 30m; 0 shell (60 mins TDT), 3 - 10m.
2	1478	East of Walker I. - depths to 50m, all soft mud.
3	1579	From Warn I. through Tancred ind Cleghorn Is. - mud, 28 - 34m.
4	1580	West side of Cape Voltaire - mud, 18 - 20m.
5	1480	North end of cape Voltaire - possible pearl bottom, 26 - 32m*.
6	1480	Voltaire Passage - possible pearl bottom, 22 - 30m*.
7	1481	Bigge Pt. - 'growth' on lumps, mud, 18 - 30m.
8	1581	Admiralty Gulf - mud and a few fish patches, 26m
9	1682	Port Warrender - mud, 10m.
10	1682	South of Myers I. - mud, 6 - 12m.
11	1582	South-west of Steep Head I. - mud, some possible small patches, 12 - 24m
12	1582	South-west of Osborne I. - garden bottom in deeper water, 28 - 52m*.
13	1482	Between Borda I. and Middle Osborne I. - mud in shallow areas, sand in deeper trenches, 16 - 28m.
14	1483	Bay to the east and north of Borda I. - mud, 12 - 18m.
15	1382	South of Low Rocks (S.E. of Long Reef) - rubble bottom, similar to Lacepede Channel; 1 MOP (120 mins TDT), 12m.
16	1382	Between Low Rocks and south end of Long Reef - garden bottom and rocks; 0 shell (60 mins TDT), 12m.
17	1283	Parry Harbour - mud, 22m.
18	1283	Cape Bougainville - uneven bottom, steep drop-offs, mud 5 - 35m.
19	1283	East of Cape Bougainville - good looking gravel bottom over a large area, 8 - 14m*.
20	1183	West of Troughton I. - possible pearl bottom, 20m*.
21	0983	Between East Holothuria Reef and Penguin Deeps - mud in deeper areas, shallower areas show hard bottom and 'growth', 25 -35m*.
22	0982	Near Combe Rk. (Holothuria Banks) - patchy bottom, 20 - 40m.*

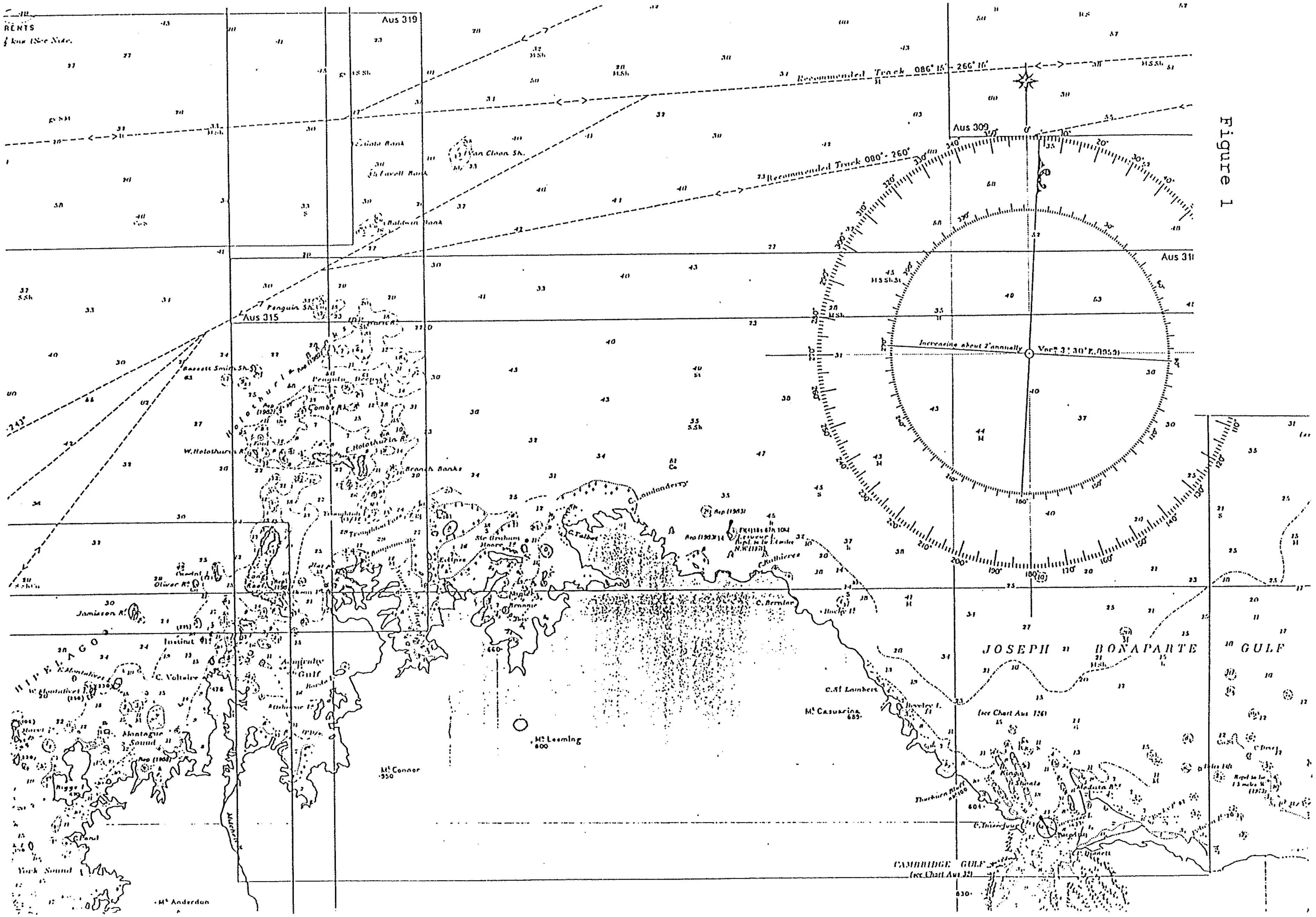
* Poor diving conditions

Table 5 (cont.)

ITEM	GRID	COMMENT
23	0981	West of the edge of Holothuria Banks - uneven bottom, hard, deep, 16 - 56m.
24	1081	West of West Holothuria Reef - undulating mud, 40 - 50m.
25	1181	North-west of Long Reef - rough bottom, 35 - 45m.
26	1382	Between Cassini I. and Pascal It. - sparse 'garden' bottom on sand, hard and soft corals; 2 MOP (180 mins TDT), 20 - 24m.
27	1482	Oyster Rk. area - mud and gravel bottom, sea whips and gorgonians; 5 MOP (180 mins TDT), 17 - 20m.
28	1381	North-east of Descartes I. - uneven bottom; mud, silt and shell, sea whips: poor pearl bottom.; 0 shell (120 mins TDT), 29 - 33m.
29	1481	Off Bigge Pt. - garden bottom; 1 MOP (120 mins TDT), 17 - 21m.
30	1480	Voltaire Passage - dirty water; Krait Bay - mud; 14 - 30m.
31	1380	Krait Bay to north end of Fenelon Passage - mostly mud, some sand, 10 - 32m.
32	1381	Fenelon Passage (north-east of Descartes I.) - 'garden' bottom; 5 MOP (260 mins TDT), 24 - 31m.
33	1381	Between Pascal It. and Oyster Rk. - 'garden' bottom; 4 MOP (160 mins TDT), 22m.
34	1382	North-east of Lafontaine I. - brown weed, dead bottom; 2 MOP (160 mins TDT), 12m.
35	1382	Oyster Rock Passage (Long Reef) - brown weed, round rocks and broken bottom; 3 MOP (160 mins TDT), 10m.
36	1381	Pascal It. - coral and 'garden' bottom in shallow (14m) changing to grit at depth (22m); 2 MOP (160 mins TDT).

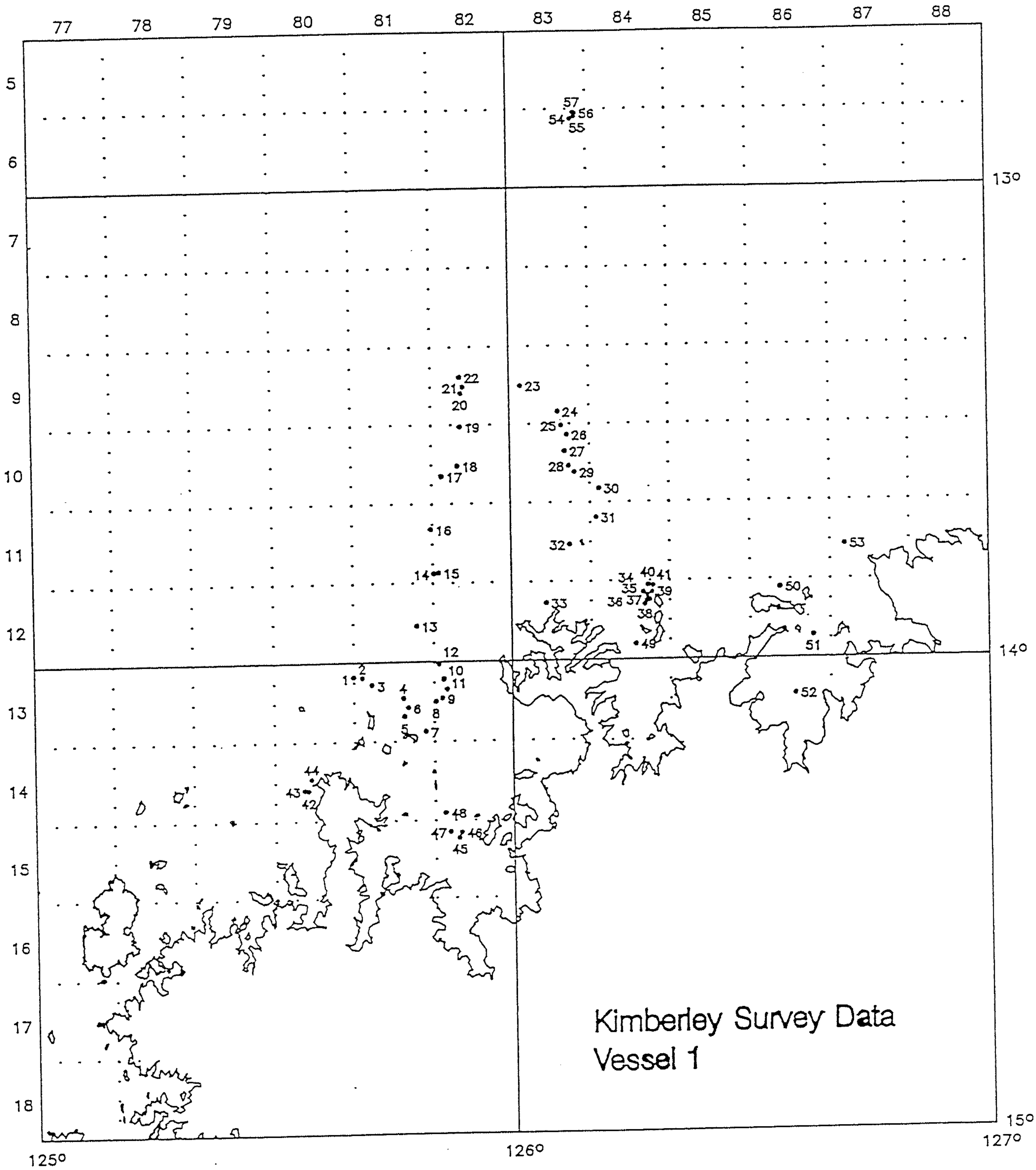
* Poor diving conditions

Figure 1



Appendix 1 - 11

Figure 2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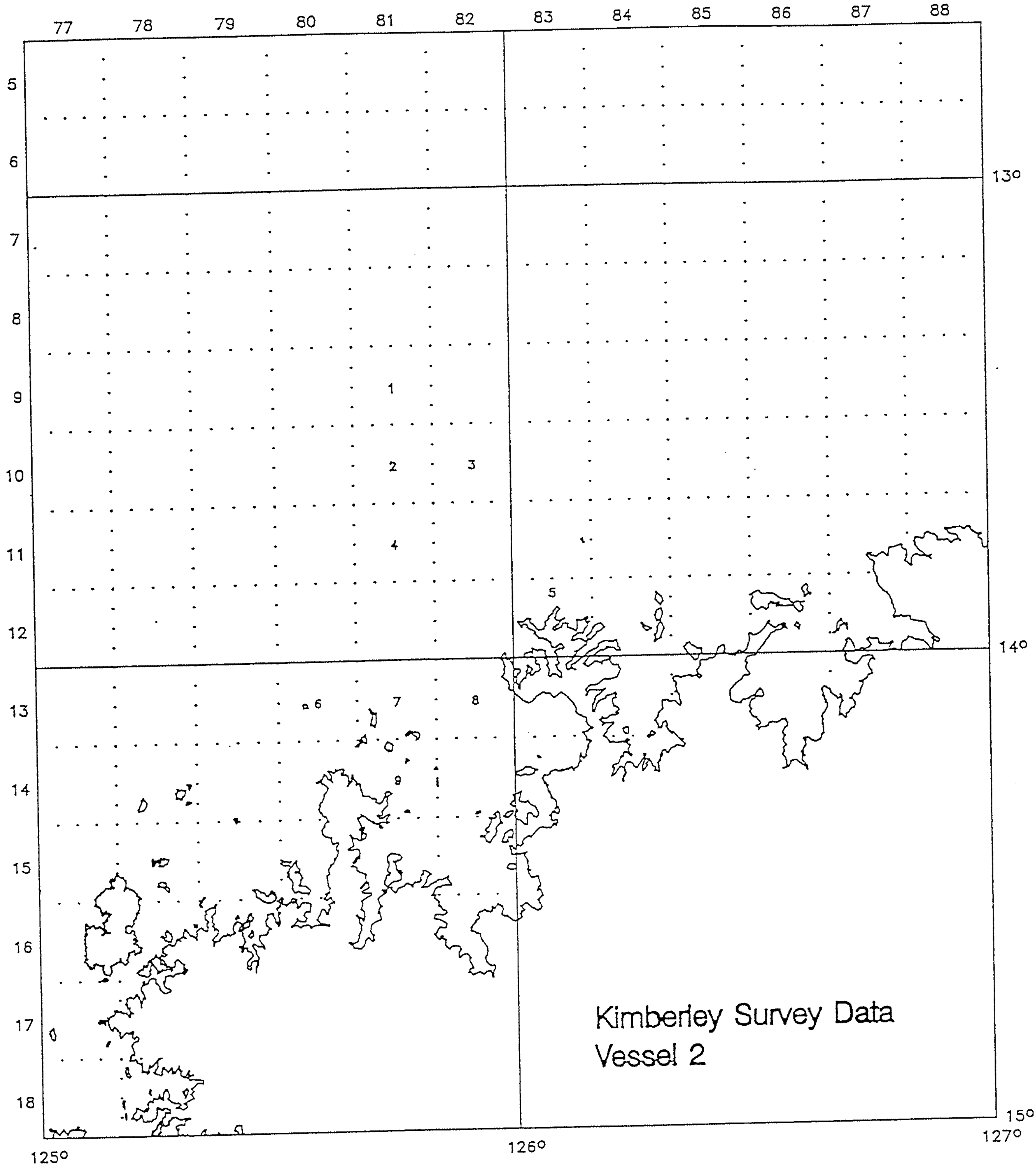
Kimberley Survey Data
Vessel 1

Figure 3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Kimberley Survey Data
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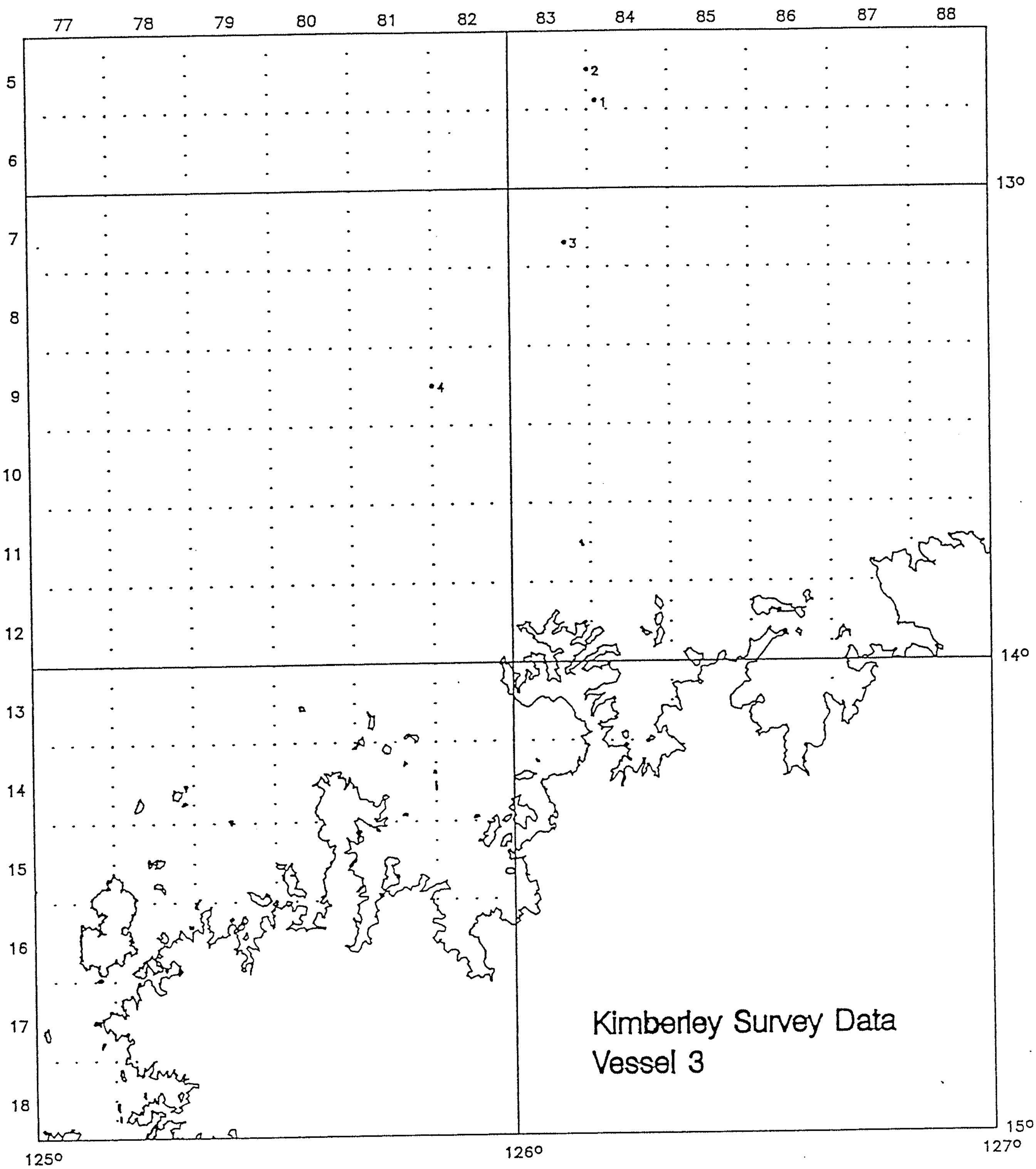
Figure 4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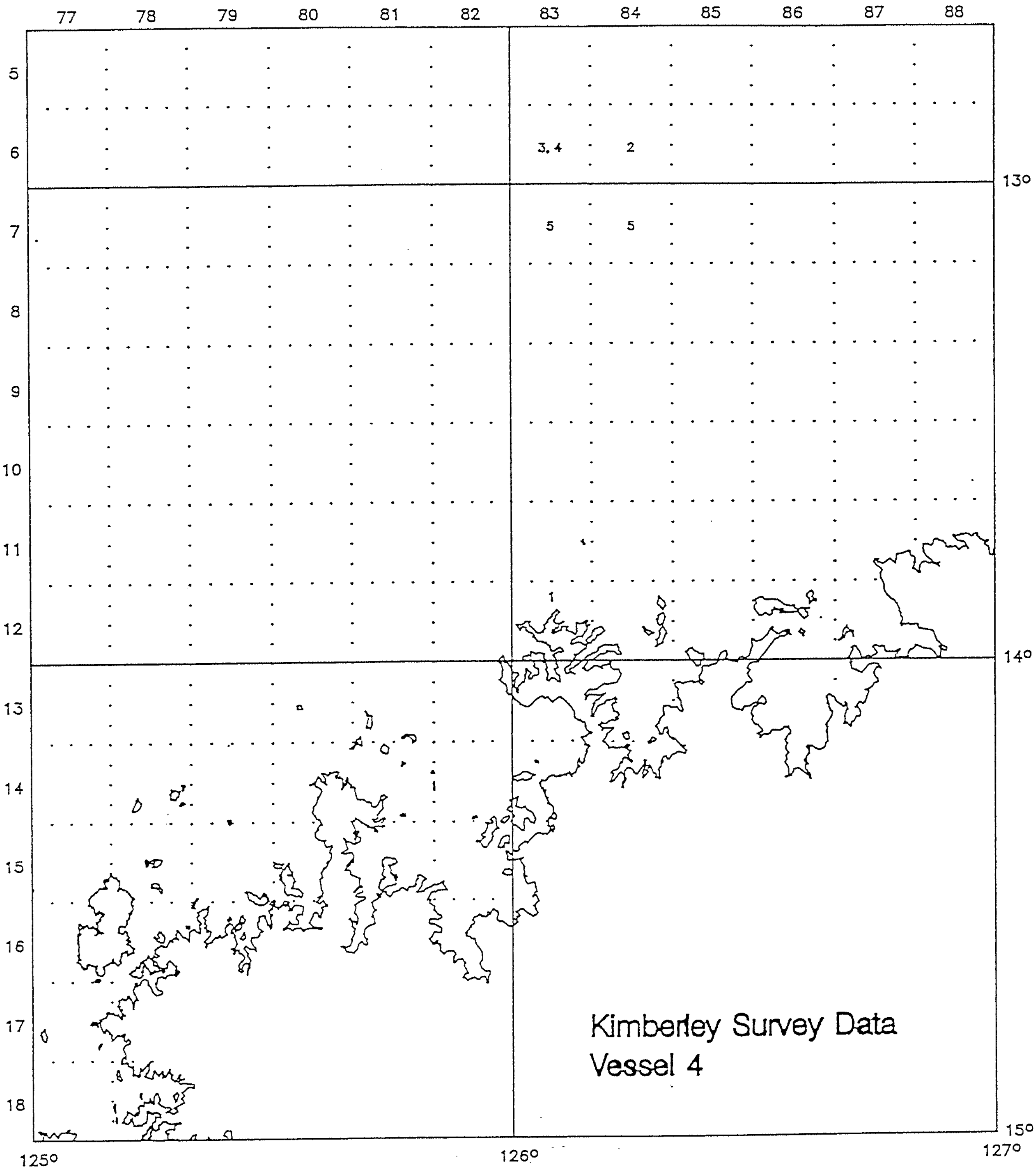
Kimberley Survey Data
Vessel 3

Figure 5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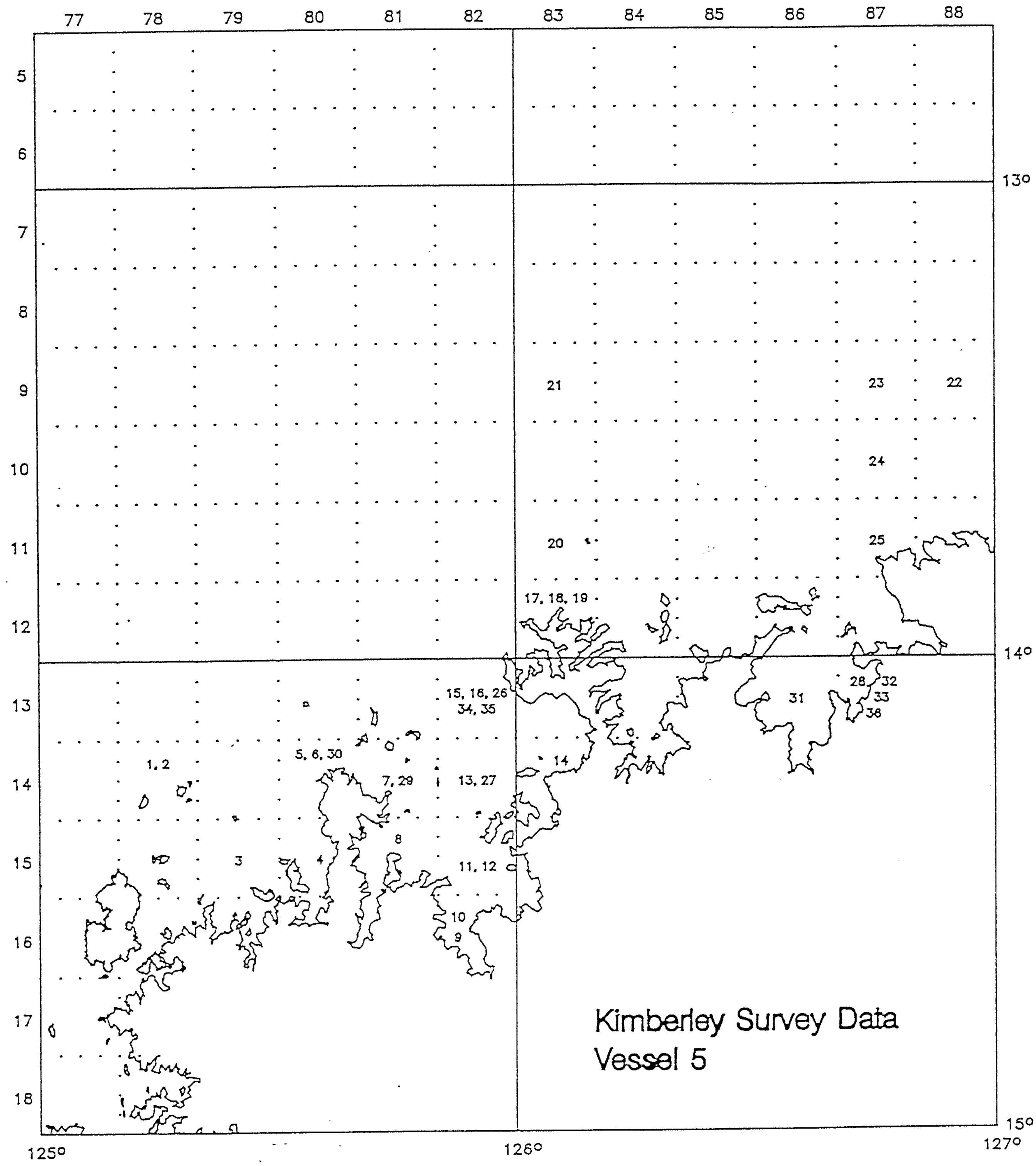
Kimberley Survey Data
Vessel 4

Figure 6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Kimberley Survey Data
Vessel 5

A SURVEY OF THE SOUTHERN SECTOR OF THE WESTERN AUSTRALIAN PEARL OYSTER FISHERY - JULY / AUGUST 1990

L.M. JOLL

Fisheries Research Division

Western Australian Fisheries Department

September 1991

INTRODUCTION

In its review of the Western Australian pearling industry the Pearling Industry Review Committee (Malone et al. 1988) recommended that, in the southern sector of the fishery (Zone 1), care be exercised in allowing the taking of oysters in addition to those already authorised, pending better information on the state of the southern sector stocks. In order to improve the understanding of the the stocks of pearl oysters in the southern sector, a survey cruise was undertaken by the research vessel 'Flinders' during July and August 1990.

MATERIALS AND METHODS

Prior to undertaking the survey the logbook data from the southern sector for the period 1980 - 1988 was reviewed to determine the areas which have been utilized by the existing licence holders over that period and the catch rates experienced. On the basis of this review (Fig. 1) the boundaries for an initial survey were set to cover the areas which had had the least exposure to commercial fishing over the period 1980 - 1988. The survey area was defined as the waters between the Dampier Archipeligo and Bedout I. (approximately 117°E to 119°E). This area covers the most northerly section of the southern zone and the buffer zone of Zone 2 (Cape Thouin to 119°E).

The Fisheries Department's 20m research vessel 'Flinders' was used for the survey. Equipment available on the vessel for the survey included a Furuno colour echo sounder for echo sounder transects and an ROV 'Mako' Underwater television for sea-bed survey and echo-sounder calibration, with a Furuno 25Kw radar and Magnavox GPS for position fixing. Two commercial pearl divers with a collective experience of 8 years diving in the pearling industry were contracted to provide diving and test fishing capabilities. The vessel commenced operations from Port Hedland on 11 July 1990 and completed the survey of the designated area on 11 August 1990. Within the survey area the vessel operated freely according to the development of apparant patterns of sea-bed types and within the constraints of weather.

Data was collected in the form of echo-sounder transects and test-diving / fishing. The echo sounder data and sea-bed descriptions from the pearl divers were categorised in the terminology of the Western Australian pearling industry. The term 'garden' represents a community of benthic marine organisms comprising soft and hard corals, sponges, bryozoans and sea whips while the adjectives 'light', 'moderate'/'medium' and 'heavy' garden indicate the density of the community. The term 'potato' indicates an assemblage of solitary ascidians. The garden and potato bottom types are commonly associated with the presence of pearl oysters. For test fishing the divers were instructed to bring up all shell seen - both large, mother-of-pearl (MOP) shell (greater than 160mm dorso-ventral shell length) and the smaller culture-sized shell (120 - 160mm DVL). Data were expressed as the catch per diver hour of the two shell types.

RESULTS

1. ECHO SOUNDER TRANSECTS

The results of the echo-sounder transects are presented on the accompanying charts (Charts 1 - 9). The bottom-type data are categorised as:

1. Mud or sand.
2. Rock (Either reef or low, flat rock)
3. Light garden
4. Moderate to heavy garden

2. DIVE DATA

The dive data are presented in Table 1. The locations of dive sites are marked on Charts 1 - 9 with diamond-shaped markers and each dive site is numbered to correspond to the list in Table 1. Dives were generally only carried out in areas where the bottom type indicated by the echo sounder suggested a potential for pearl oysters to be found. However, in some cases the type of bottom revealed by the dive was not always consistent with the echo-sounder interpretation. In other cases the area of apparantly good bottom was fairly small and the vessel was unable to deploy the diver exactly in the area covered by the echo sounder survey. Navigation problems caused by poor radar reception and periods of non-availabilty of GPS satellite coverage contributed to the difficulties in placing divers on areas of good bottom detected by the echo sounder transects.

On the basis that 'good' bottom could be taken as those areas where some shell was caught (either MOP or culture shell), the average catch per diver hour for drifts on 'good' bottom was determined, both on an overall and a depth stratified basis (0 - 18m and 19 - 35m). To allow for comparisons with the results of an earlier 'Flinders' survey in the area north-west of Broome (Penn and Dybdahl, 1988), the dive data were also re-calculated using the categorization of culture and MOP shell used in this earlier survey (i.e. shells smaller than 204mm were categorized as culture shell)

TABLE 2. AVERAGE CATCH RATES OF SHELL ON "GOOD" BOTTOM
(i.e. bottom on which shell was caught)

	CULTURE	MOP	CULTURE	MOP
	(Culture shell 120 - 160mm)		(Culture shell 120 - 203mm)	
0 - 18m (36 dives)	5.4	15.0	9.4	10.9
19 - 35m (61 dives)	3.3	18.1	8.2	13.3
OVERALL	4.2	16.8	8.7	12.3

DISCUSSION

The survey found a number of areas of garden and potato bottom which appeared to be promising ground for finding pearl oysters. The catches of pearl oysters by the divers, however, did not fully reflect the promising appearance of these areas. Nevertheless, with only two divers and limited time to fully explore the areas, the catches by the divers cannot be expected to fully represent the potential of the area.

The echo sounder transects suggested that, in general, the most promising areas were in fairly deep water (20m and deeper) and between 15 and 20 miles offshore. Between the coast and the more promising offshore areas the bottom was generally either barren sand or mud, with some lines of reefy bottom associated with extensions of the Geographe Shoals. The primary exception to the general indications of better areas offshore was an area around North Turle Islet. There were also a few small, isolated areas of apparantly good potential in shallower water, nearer the coast (e.g. around dive sites 80, 87, 104 and 126).

Comparison of the results from this survey with the 1987 'Flinders' survey north-west of Broome (Penn and Dybdahl, 1988) provide some basis for measuring the overall potential of the survey area. The overall average catch rate of culture shell (defined in that survey as shell <204mm) on 'good' bottom was 7.25 shells/diver hour, compared with an equivalent figure for the present survey of 8.7 shells/diver hour. To determine what these figures may imply in terms of total production of shell from an area, the total catch of commercial culture shell from the six logbook grids which comprised the 1987 survey area was obtained from logbook data. In the 3 years following the survey for which data is available (1988 to 1990) the total annual catch of commercial culture shell from the six grids (3358, 3359, 3458, 3459, 3558 and 3559) has been above 5000 shell. By comparison, the area covered by the present survey is roughly equivalent to 26 logbook grids. On the basis that there are similar proportions of 'good' and 'poor' bottom in the two survey areas, the data suggests that a sustainable catch considerably higher than 5000 shell could be expected to be taken from the Zone 1 survey area.

While this report was in preparation, permission was granted to two licencees from Zone 3 of the pearl oyster fishery to take 5000 oysters each in the 'buffer' zone of Zone 2 (119°E to Cape Thouin). Most of the fishing effort expended in the take of these oysters was in the apparantly promising areas around North Turtle Islet (logbook grid 4840). The results of these commercial operations also provide an insight into the potential of the area. The mean daily catch rates of culture shell experienced by each of the vessels ranged from 6.3 to 27.1 shell/diver hour, with an overall mean of 17.7 shell/diver hour (Vessel A) and 14.3 to 37.9 shell/diver hour, with an overall mean of 23.4 shells/diver hour (Vessel B). These catch rates are more than adequate from a commercial point of view. Furthermore, virtually all the 10 000 pearl oysters were taken within a single logbook grid.

The survey indicates that there are some areas in this sector of the fishery which could provide useful fishing grounds for pearl oysters and which have the potential to produce a substantial sustainable catch. However, there is a need to produce a more complete picture of the area's potential to determine what that sustainable catch might be. Given the limitations of research surveys, the most appropriate means of producing the data would be through the activities of commercial pearling vessels in the area. The current arrangements for the take of pearl shell by the pearling industry, however, do not provide a strong incentive for exploratory commercial fishing. A fuller assessment of the commercial prospects of the area will therefore have to await the results of further commercial fishing activities in the area.

ACKNOWLEDGEMENTS

On-board recording of echo-sounder transects and dive data was carried out by A.T. Hancock and R.R. Allison from the Research Division of the Fisheries Department. Diving support from Pearl Coast Divers was provided by G.R. Johnston and C.A. Sharp. Funding for the survey was provided from the Western Australian Fisheries Research and Development Trust Fund.

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Malone F.J., Hancock D.A. and Jeffries B., 1988. Final report of the Pearling Industry Review Committee. Fisheries Management Paper 17, Western Australian Fisheries Department 216pp.

Penn J.W. and Dybdahl R., 1988. A research vessel survey of pearl oyster and prawn resources north-west of Broome, Western Australia. Fisheries Report Western Australia 81, 24pp.

TABLE 1 **DIVE DATA**

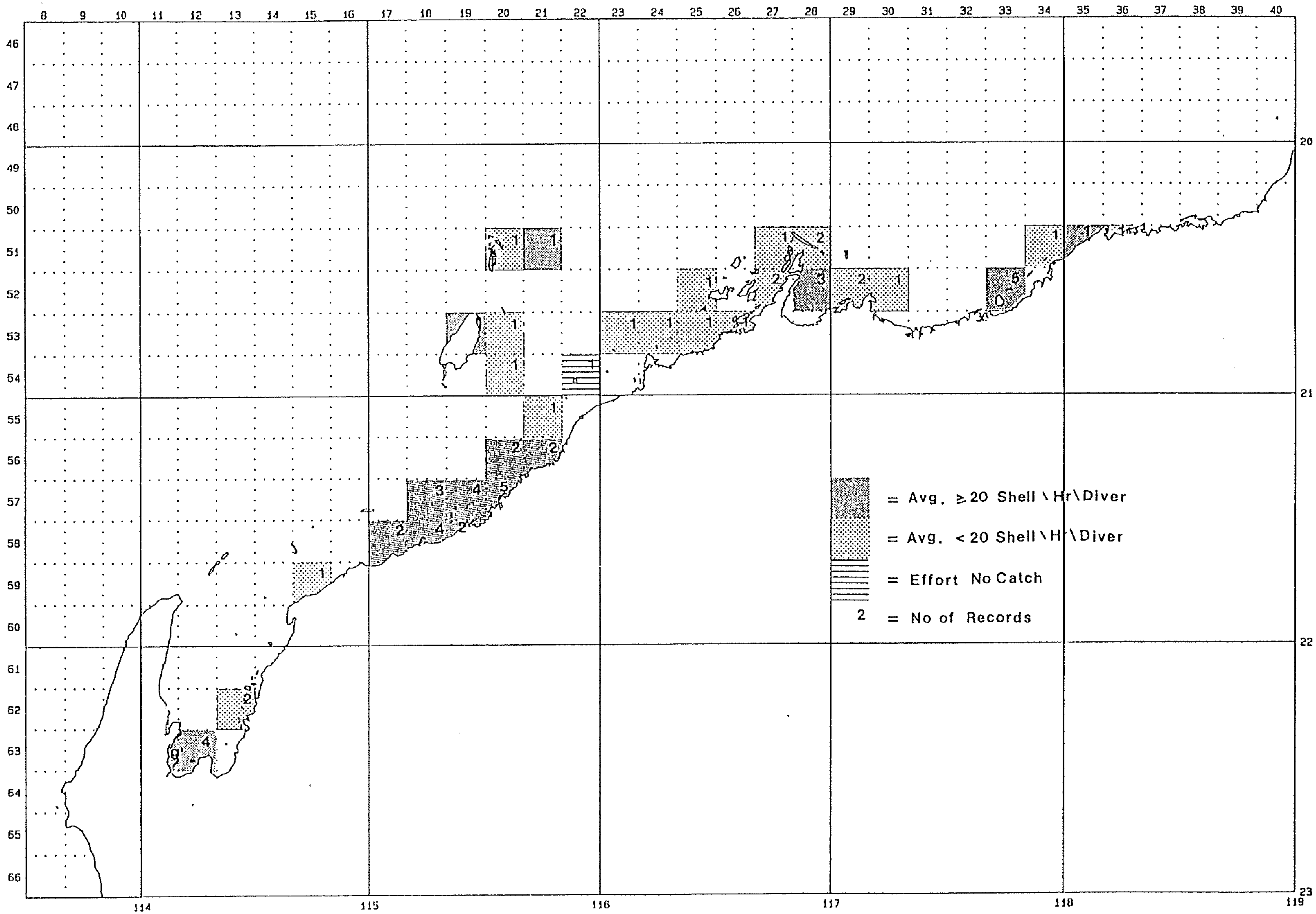
[TBT = Total bottom time (i.e. dive duration x no. of divers)]

DIVE N°.	**DEPTH (M)**	**CATCH MOP**	**CATCH CULT**	**TBT (MINS)**	**CATCH/ DIVER HR MOP**	**CATCH/ DIVER HR CULT**	**COMMENTS**
1	11	4	0	50	4.8	0	Med - heavy garden on rock (Fish bottom)
2	13	2	0	15	8.0	0	Med - heavy garden on rock (Fish bottom)
3	14	0	0	16	0	0	Light garden on silt
4	20	0	0	30	0	0	Sand
5	17	0	0	46	0	0	Light garden on sand
6	12	0	0	22	0	0	Light garden on muddy sand / Garden on rocks in channels.
7	12	5	1	80	3.8	0.8	Gutter - sand on rock / Heavy garden on sides of gutter.
8	12	2	1	8	15.0	7.5	Heavy garden on silt.
8A	12	2	2	14	8.6	8.6	Thin sand over rock / light garden
9	12	-	-	2	-	-	Spot dive; V. light garden
10	10	11	5	21	31.4	14.3	Light - med garden on silt; good shell ground
11	10	4	1	52	4.6	1.2	Light garden on sand / Heavy garden on ridge (but no shell)
12	10	-	-	7	-	-	Spot dive; weed on sand/rock
13	15	3	1	11	16.4	5.5	Hard bottom
14	17	1	0	10	6.0	0	Hard bottom
15	16	-	-	6	-	-	Spot dive; hard bottom
16	35	0	0	15	0	0	Light garden; looks good, no shell
17	27	0	0	10	0	0	Hard bottom and light garden patches
18	16	2	0	22	5.5	0	Light garden on silt at edge of reef
19	28	0	0	20	0	0	Light garden on reef
20	19	6	0	20	18.0	0	Heavy garden on reef
21	26	0	0	9	0	0	Light garden on sand
22	22	1	0	5	0	0	Reef, sand and light garden
23	18	0	0	17	0	0	Heavy garden on sand; no shell
24	12	0	0	5	0	0	Light garden on reef
25	15	0	0	10	0	0	Sparse garden on reef
26	23	0	1	30	0	2.0	Light garden and potato on silt
27	22	4	0	24	10.0	0	Light garden on sand
28	25	6	1	17	21.2	0	Light garden on sand
29	24	3	0	25	7.2	0	Heavy garden on silt
30	16	4	3	26	9.2	6.9	Light - med. garden on sand
31	10	1	0	10	6.0	0	Light garden on sand
32	7	0	0	5	0	0	Sand
33	4	0	0	12	0	0	Sand
34	16	0	0	5	0	0	V. light garden on sand
35	18	3	1	29	6.2	2.1	Light - med. garden on sand/reef
36	17	7	3	50	8.4	3.6	Light garden on sand
37	16	0	0	5	0	0	Light garden turning to sand
38	19	1	2	20	3.0	6.0	Sand and light garden
39	15	5	0	22	13.6	0	Light garden on sand adjoining reef
40	13	3	1	20	9.0	3.0	Light garden on sand adjoining reef
41	14	2	0	12	10.0	0	Light garden on sand adjoining reef
42	15	0	3	27	6.7	0	Med. garden on light reef
43	24	1	0	8	7.5	0	Med. garden on silt
44	26	23	7	60	23.0	7.0	Med. garden on silt
45	19	24	10	16	90.0	37.5	Med. garden and potato on silt adjoining reef
46	18	0	0	5	0	0	Rock

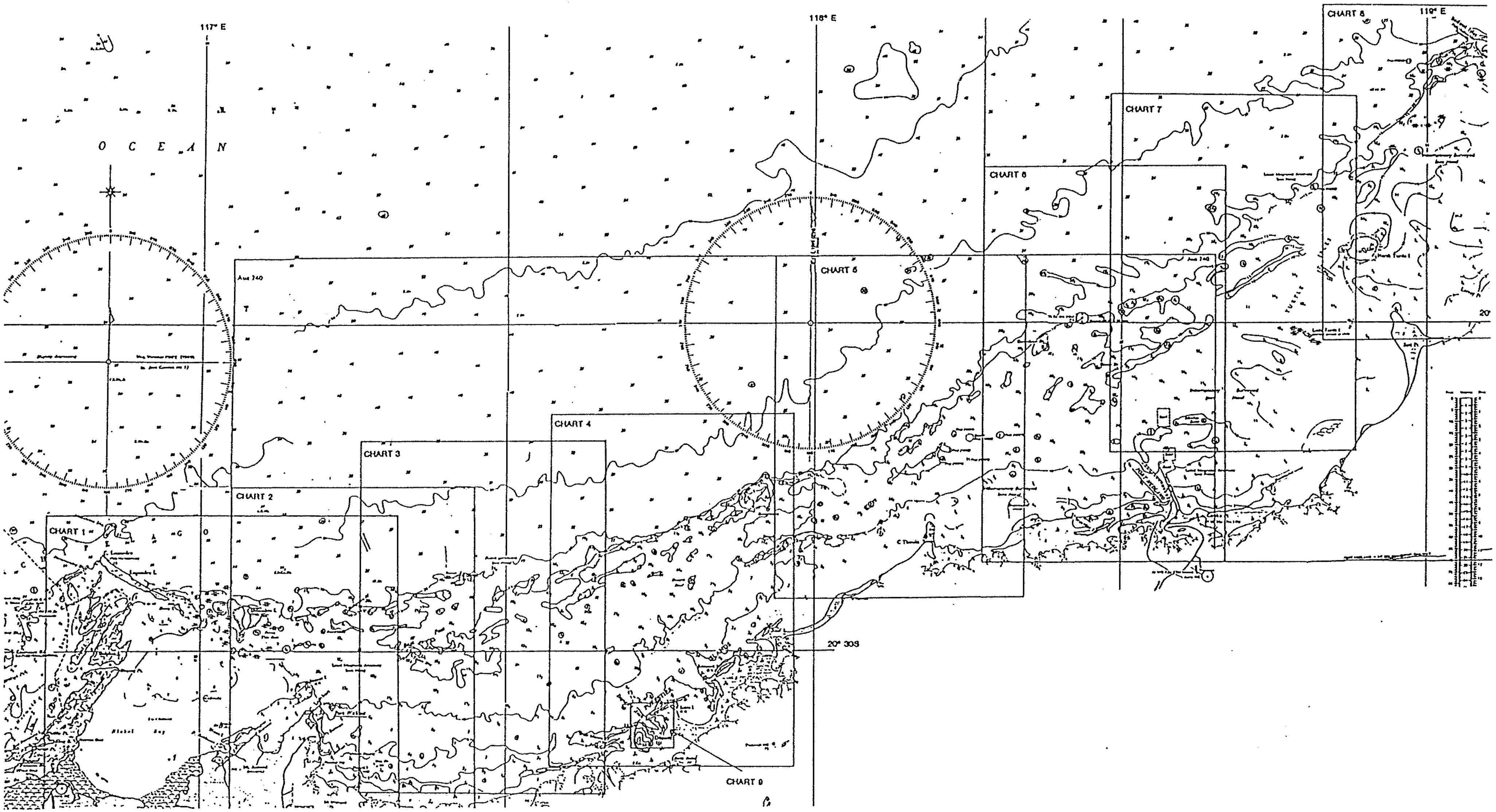
DIVE N°.	DEPTH (M)	CATCH MOP	CATCH CULT	TBT (MINS)	CATCH/ DIVER HR MOP	CATCH/ DIVER HR CULT	COMMENTS
47	28	5	0	44	6.8	0	Med. garden on silt
48	28	9	1	10	54.0	6.0	Med. garden on silt
49	28	1	2	10	6.0	12.0	Med. garden on silt
50	27	0	1	8	0	7.5	Sand
51	28	6	1	16	22.5	3.8	Reef / sand / Med. garden (looks good)
52	29	12	3	10	72.0	18.0	Heavy garden on silt
53	30	8	1	10	48.0	6.0	Med. garden / sand
54	32	1	0	12	5.0	0	V. light garden on sand
55	34	3	0	13	13.8	0	Reef / sand
56	32	0	0	5	0	0	V. light garden on hard sand
57	27	1	0	10	6.0	0	Light garden on reef / sand
58	22	3	2	22	8.2	5.5	Sand / med. garden / rock
59	28	2	0	12	10.0	0	Light garden on silt
60	28	1	0	8	7.5	0	Light garden on sand / reef
61	31	1	0	7	8.6	0	Reef
62	24	0	0	8	0	0	Reef / sand
63	28	0	0	7	0	0	Light garden on silt
64	27	4	0	13	18.5	0	Light - med. garden on silt and sand
65	29	0	0	11	0	0	Light - med. garden on silt and sand - v.patchy
66	29	3	0	15	12.0	0	Light garden on sand - v.patchy
67	28	0	0	10	0	0	Light garden on sand / reefy patches
68	31	0	0	10	0	0	Sand with light garden
69	35	1	0	11	5.5	0	Light garden on sand
70	29	4	1	17	14.1	3.5	Soft 'reef' / reef / light garden on sand
71	30	3	0	40	4.5	0	Light garden on silt / reef
72	4	0	0	14	0	0	Light garden and weed on reef
73	13	0	0	5	0	0	Light garden on silt
74	11	0	0	10	0	0	Med. garden on sand / reef
75	7	0	0	14	0	0	Sand
76	9	1	0	11	5.5	0	Reef / med. garden
77	8	0	0	5	0	0	Sand
78	6	0	0	12	0	0	Flat reef, some boulders
79	12	3	0	18	10.0	0	Algae / Med. garden on sand
80	12	6	0	12	30.0	0	Med. garden on heavy reef
81	19	8	2	35	13.7	3.4	Reef / flat reef / sand
82	17	4	0	17	14.1	0	Med. garden on sand / reef
83	17	3	1	30	6.0	2.0	Med. garden on flat reef
84	6	1	1	10	6.0	6.0	Reef with med. garden / mud
85	6	0	0	20	0	0	Growth on ridges / mud
86	6	12	4	30	24.0	8.0	Drifted along reef edge
87	5	21	11	20	63.0	33.0	Garden on rock / patches of mud
88	18	5	0	22	13.6	0	Reef / sand / med. garden on flat reef
89	19	8	0	40	24.0	0	Reef / light garden on sand
90	22	5	0	10	30.0	0	Hard reef (fish bottom)
91	6	3	0	18	10.0	0	Hard flat reef
92	8	0	0	10	0	0	Hammer shell and low coral on soft bottom
93	13	3	0	8	22.5	0	Hard flat reef and light garden
94	25	1	1	9	6.7	6.7	Clumps of reef and garden / silt
95	27	0	0	10	0	0	Patches of med. garden on silt / sand
96	24	0	0	25	0	0	Light garden on silt
97	23	0	0	7	0	0	Light garden on gritty sand / bare ground
98	22	2	0	30	4.0	0	Patches of good garden, rest low, light garden
99	24	1	0	11	5.5	0	Light garden on silt
100		26	4	0	16	15.0	0 Reef and sea whips / sand
101		28	0	0	12	0	0 Sea whips on coarse sand

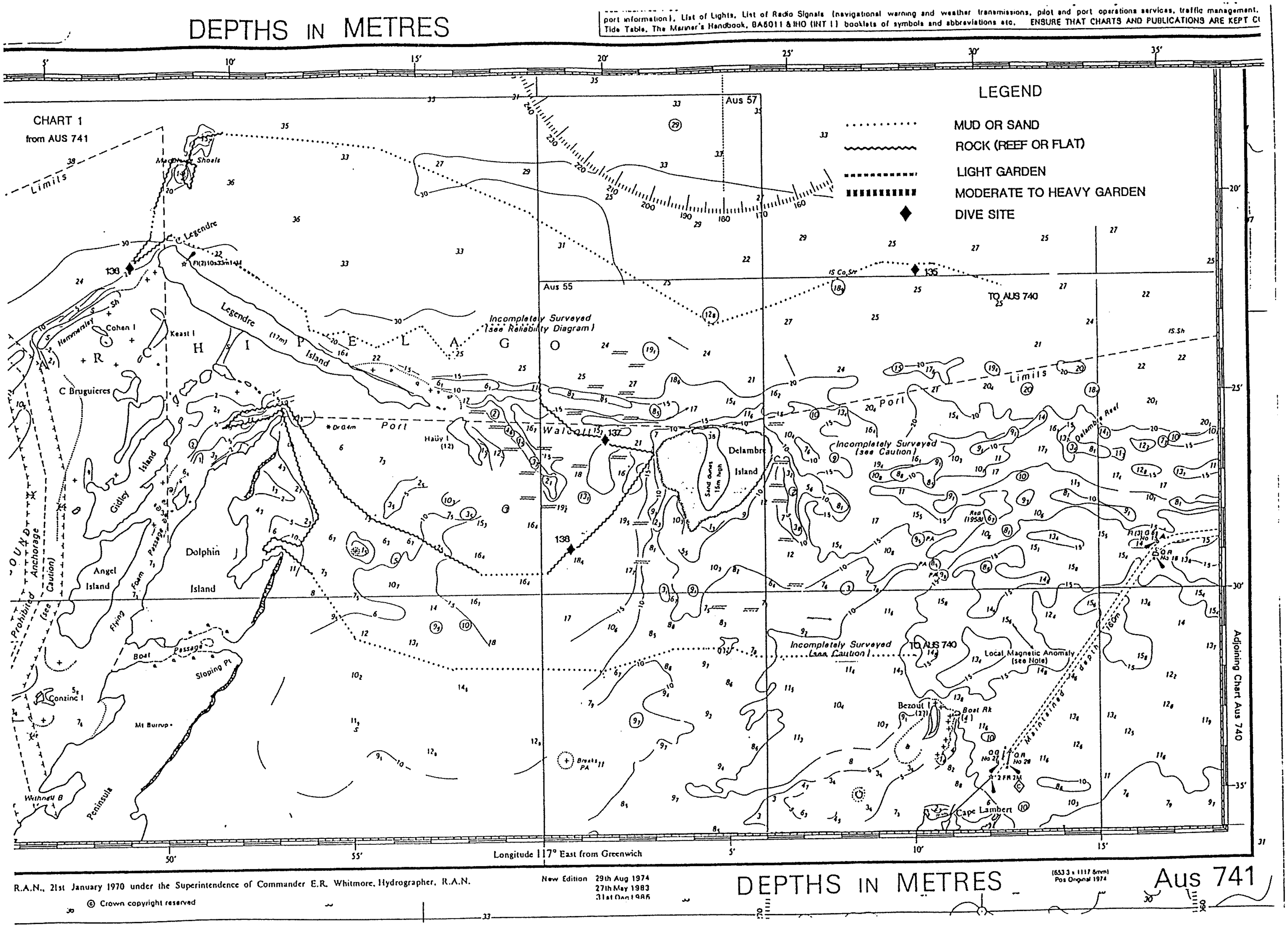
DIVE N°.	DEPTH (M)	CATCH MOP	CATCH CULT	TBT (MINS)	CATCH/ DIVER HR MOP	CATCH/ DIVER HR CULT	COMMENTS
102	29	0	0	12	0	0	Reefy bottom / sand
103	18	14	0	18	46.7	0	Reefy bottom / med. garden on sand
104	7	44	3	20	132.0	9.0	Heavy garden at bottom of basin / terraces of reef / sand in shallow
105	3	0	0	10	0	0	Sand
106	3	0	0	8	0	0	Mud
107	11	2	0	12	0	0	Low light garden on silt
108	14	0	0	6	0	0	Sand
109	13	0	0	5	0	0	Heavy reef / broken bottom / sand and dead shell
110	24	4	0	13	18.5	0	V.light garden on sand
111	24	3	0	17	10.6	0	V.light garden on sand
112	28	0	0	10	0	0	Med. - heavy garden (similar to Compass Rose)
113	27	0	0	6	0	0	Light garden (dive aborted - gear problem)
114	28	0	0	5	0	0	Sand
115	29	0	0	5	0	0	Sand with patches of light garden
116	23	0	0	12	0	0	V.light garden on sand
117	20	1	0	20	3.0	0	Heavy reef and light garden
118	23	1	0	20	3.0	0	Low light garden on silt
119	24	1	1	10	6.0	6.0	Reef and med. garden on silt
120	24	0	0	8	0	0	Reef and med. garden on silt
121	30	0	0	8	0	0	Hard reef with garden / reef with sand covering
122	26	5	0	23	13.0	0	Med. garden on silt
123	16	8	0	15	32.0	0	Flat reef with gritty sand and low growth / soft sand
124	17	2	0	10	12.0	0	Soft sand
125	13	16	0	20	48.0	0	Med. to heavy garden
126	14	20	1	20	60.0	3.0	Med. to heavy garden
127	30	0	1	10	0	6.0	V.light garden on sand
128	27	0	0	11	0	0	V.light garden on sand
129	30	0	1	10	0	6.0	Reef and sand
130	27	0	0	12	0	0	Med. garden on silt
131	27	26	1	20	78.0	3.0	Heavy garden on soft, silty bottom
132	27	10	0	10	60.0	0	Heavy garden on soft, silty bottom
133	31	11	0	20	33.0	0	Med. garden on sand / garden on reef
134	30	22	0	30	44.0	0	Med. garden on sand
135	32	1	0	14	4.2	0	Sandy with patches of light garden and whips
136	26	0	0	7	0	0	Light garden on hard reef
137	20	3	2	13	13.8	9.2	Light garden on hard reef
138	20	3	0	12	15.0	0	Light garden on hard, flat reef
139	20	-	-	4	-	-	Spot dive, soft silt over hard, flat reef
140	33	0	0	10	0	0	Sandy with sea whips
141	31	2	0	22	5.5	0	Light garden and sea whips on sand
142	32	0	0	22	0	0	V.light garden on silt over harder bottom
143	31	1	0	10	6.0	0	Low light garden on sand over harder bottom
144	32	3	0	20	9.0	0	Sand with patches of med. garden
145	26	26	1	28	55.7	2.1	Med. garden on silt over rock
146	27	17	5	25	40.8	12.0	Sand / Med. garden on sand / sand
147	28	26	1	23	67.8	2.6	Low med. garden and potato on silt
148	28	1	0	17	3.5	0	Sand on reef ridge
149	29	1	0	11	5.5	0	Med. garden on sand
150	32	-	-	6	-	-	Spot dive; sand and reef
151	30	-	-	5	-	-	Spot dive; sand and reef
152	22	2	1	13	9.2	4.6	Mud / hard reef
153	22	0	0	19	0	0	Med. garden on sand
154	21	7	1	16	26.3	3.8	Med. garden over soft 'reef'
155	35	-	-	5	-	-	Spot dive; sand and reef
156	30	0	0	10	0	0	Sand and reef

FIG. 1 AVERAGE CATCH RATES BY BLOCK IN THE SOUTHERN SECTOR 1980 - 1988



OVERVIEW OF SURVEY AREAS COVERED ON CHARTS 1 - 9




DEPTHS IN METRES
List of Lights, List of Radio Signals (navigational warning and weather transmissions, pilot and port operations services, traffic management, port information), Tide Table, The Mariner's Handbook, BA5011 & IHO (INT 1) booklets of symbols and abbreviations etc. ENSURE THAT CHARTS AND PUBLICATIONS ARE KEPT C
LEGEND
MUD OR SAND
ROCK (REEF OR FLAT)
LIGHT GARDEN
MODERATE TO HEAVY GARDEN
DIVE SITE
CHART 1
from AUS 741
Aus 57
Aus 55
Limits
C. Legendre
Legendre Island
Cohen I
Keast I
C Bruguieres
Gidley Island
Dolphin Island
Angel Island
Flying Foam Passage
Boat Passage
Sloping Pt
Conzinc I
Mt Burrup
Withnell B
Peninsula
Prohibited Anchorage (see Caution)
Port Walcott
Hauy I (12)
Delambre Island
Sand dunes 15m high
Incompletely Surveyed (see Reliability Diagram)
Incompletely Surveyed (see Caution)
Delambre Reef
TO AUS 740
Local Magnetic Anomaly (see Note)
Bezout I
Boat Rk
Cape Lambert
Breaks PA
Adjoining Chart Aus 740
Longitude 117° East from Greenwich
R.A.N., 21st January 1970 under the Superintendence of Commander E.R. Whitmore, Hydrographer, R.A.N.
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New Edition 29th Aug 1974
27th May 1983
31st Dec 1986
DEPTHS IN METRES
Aus 741

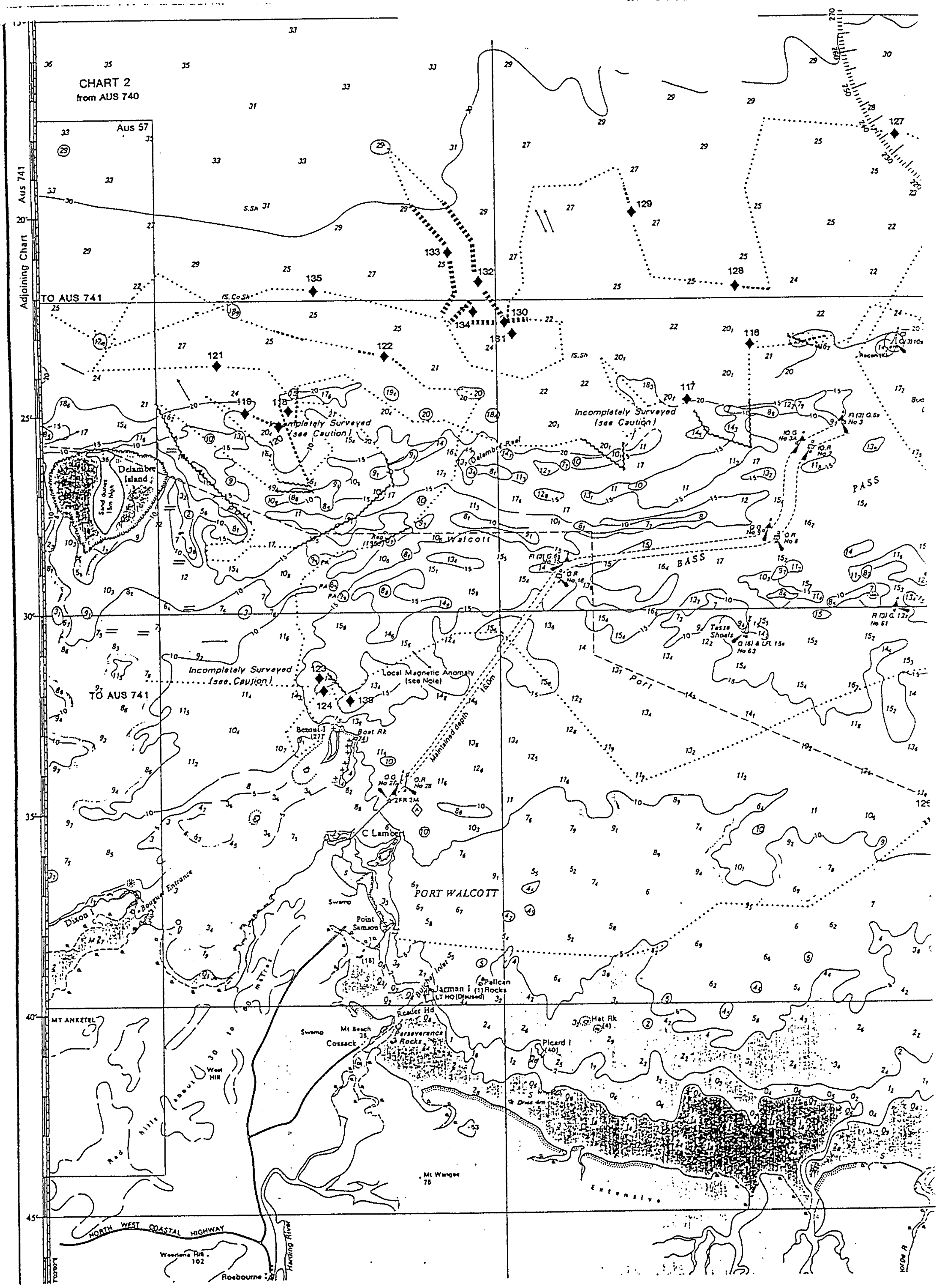
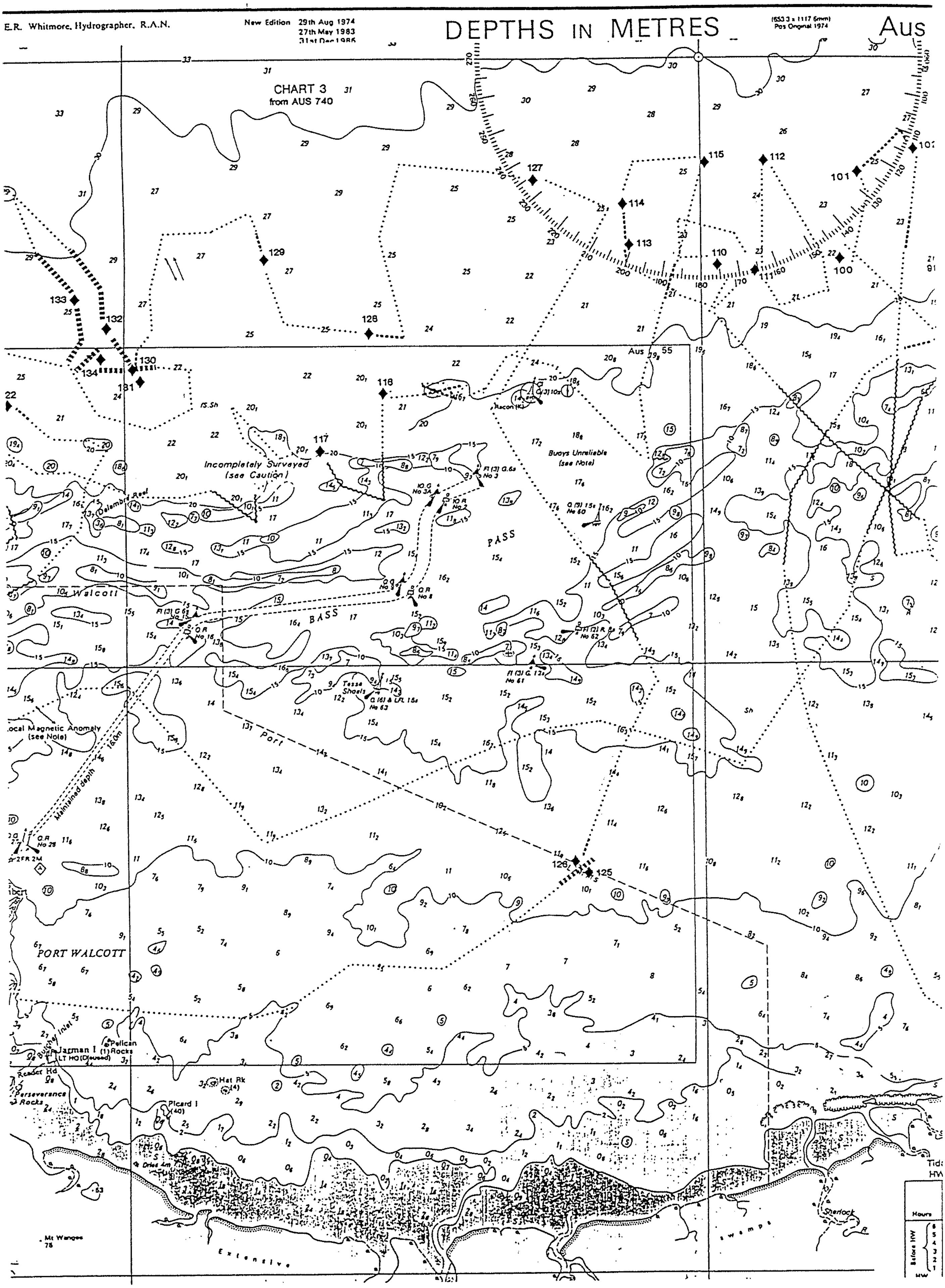


CHART 2
from AUS 740
Aus 57
Adjoining Chart Aus 741
TO AUS 741
Delambre Island
Sand dunes 15m high
Delambre Reef
Incompletely Surveyed (see Caution)
Walcott
BASS
PASS
Port
Tessa Shoals
Local Magnetic Anomaly (see Note)
Maintained depth 16.0m
Bezout I
Boat Rk
C Lambert
PORT WALCOTT
Point Samson
Dixon I
Bouguer Entrance
Jarman I
LT HO (Disused)
Pelican Rocks
Reader Hd
Perseverance Rocks
Mt Beach
Cossack
Swamp
Picard I
Hat Rk
Butcher Inlet
MT ANKETEL
West Hill
Red hills about 30 to 60 metres
Mt Wangee 75
Extensive
NORTH WEST COASTAL HIGHWAY
Weerlana Hill 102
Roebourne
Harding River
Incompletely Surveyed (see Caution)
S.Sh
fS.Co.Sh
135
133
132
134
130
131
129
128
127
122
121
119
118
120
117
116
123
124
139
125



E.R. Whitmore, Hydrographer, R.A.N.
New Edition 29th Aug 1974
27th May 1983
DEPTHS IN METRES
Aus
CHART 3
from AUS 740
Incompletely Surveyed
(see Caution)
Buoys Unreliable
(see Note)
PASS
BASS
Walcott
Delambre Reef
Tessa Shoals
Port
Local Magnetic Anomaly
(see Note)
Maintained depth 16.0m
PORT WALCOTT
Jarman I
Pelican Rocks
Hat Rk
Picard I
Perseverance Rocks
Reader Hd
Butcher Inlet
Sherlock
Mt Wangee
Extensive
swamps
Hours
Before HW
HW

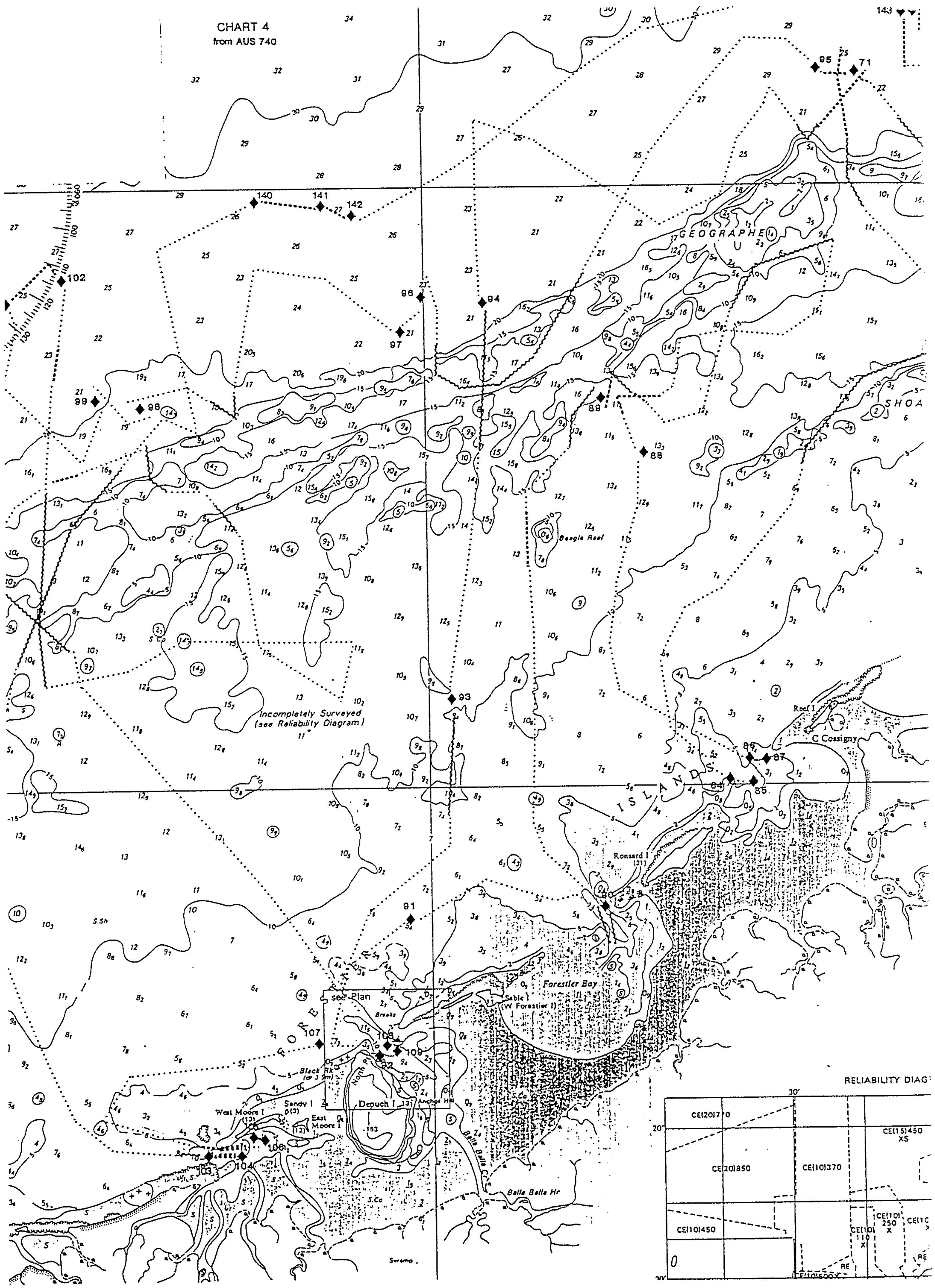


CHART 4
from AUS 740
GEOGRAPHE
SHOA
Beagle Reef
Incompletely Surveyed
(see Reliability Diagram)
ISLANDS
FORESTIER
Reef I
C Cossigny
Ronsard I
Forestier Bay
Sable I
(W Forestier I)
See Plan
Breaks
Black Rk
Depuch I
Anchor Hill
Sandy I
West Moore I
East Moore I
Balla Balla Hr
Swamp
RELIABILITY DIAG
CE(20)770
CE(15)450
CE(20)850
CE(10)370
CE(10)450

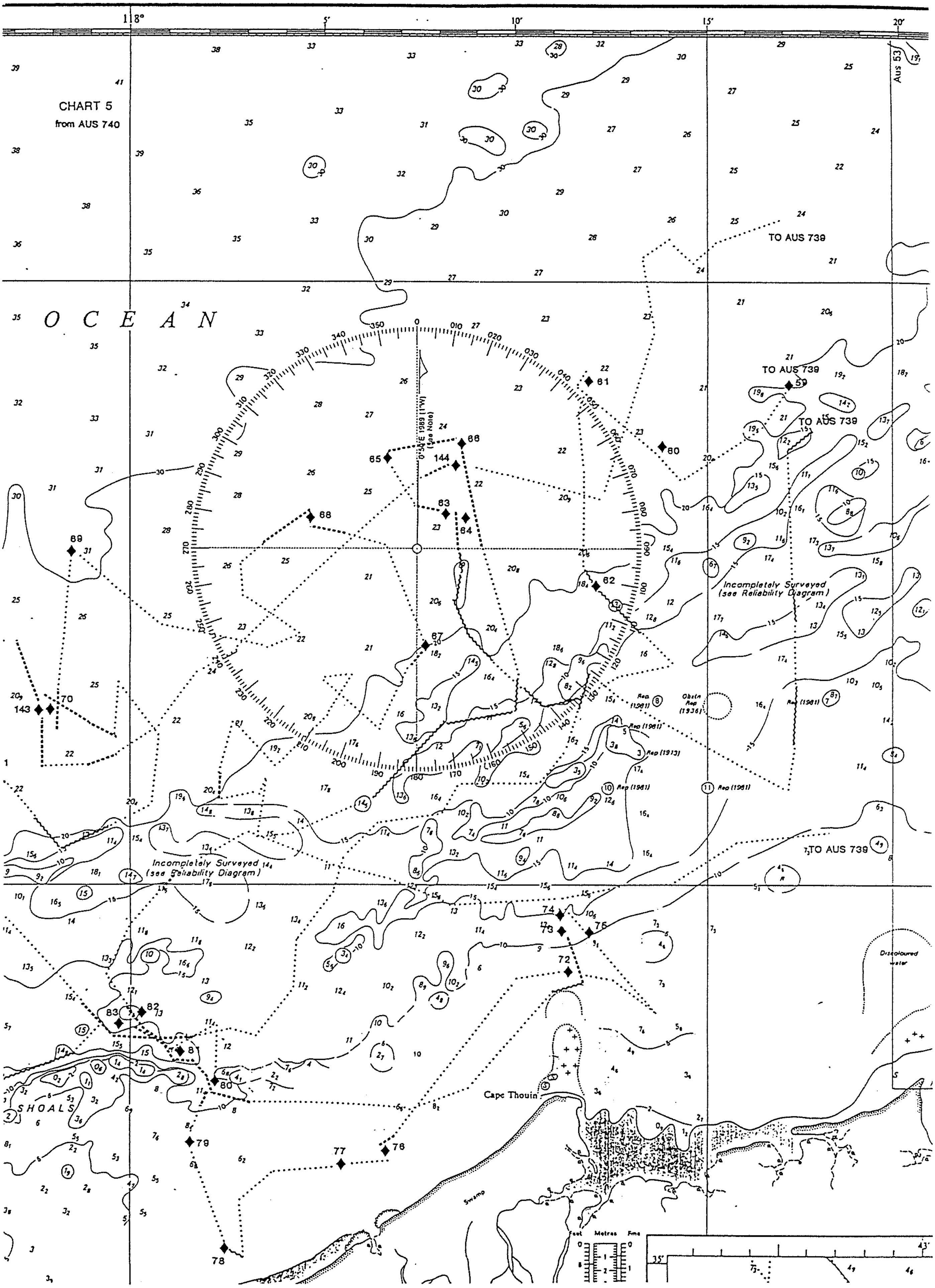


CHART 5
from AUS 740
OCEAN
TO AUS 739
TO AUS 739
TO AUS 739
TO AUS 739
Incompletely Surveyed
(see Reliability Diagram)
Incompletely Surveyed
(see Reliability Diagram)
SHOALS
Cape Thouin
Swamp
Discoloured water
Aus 53

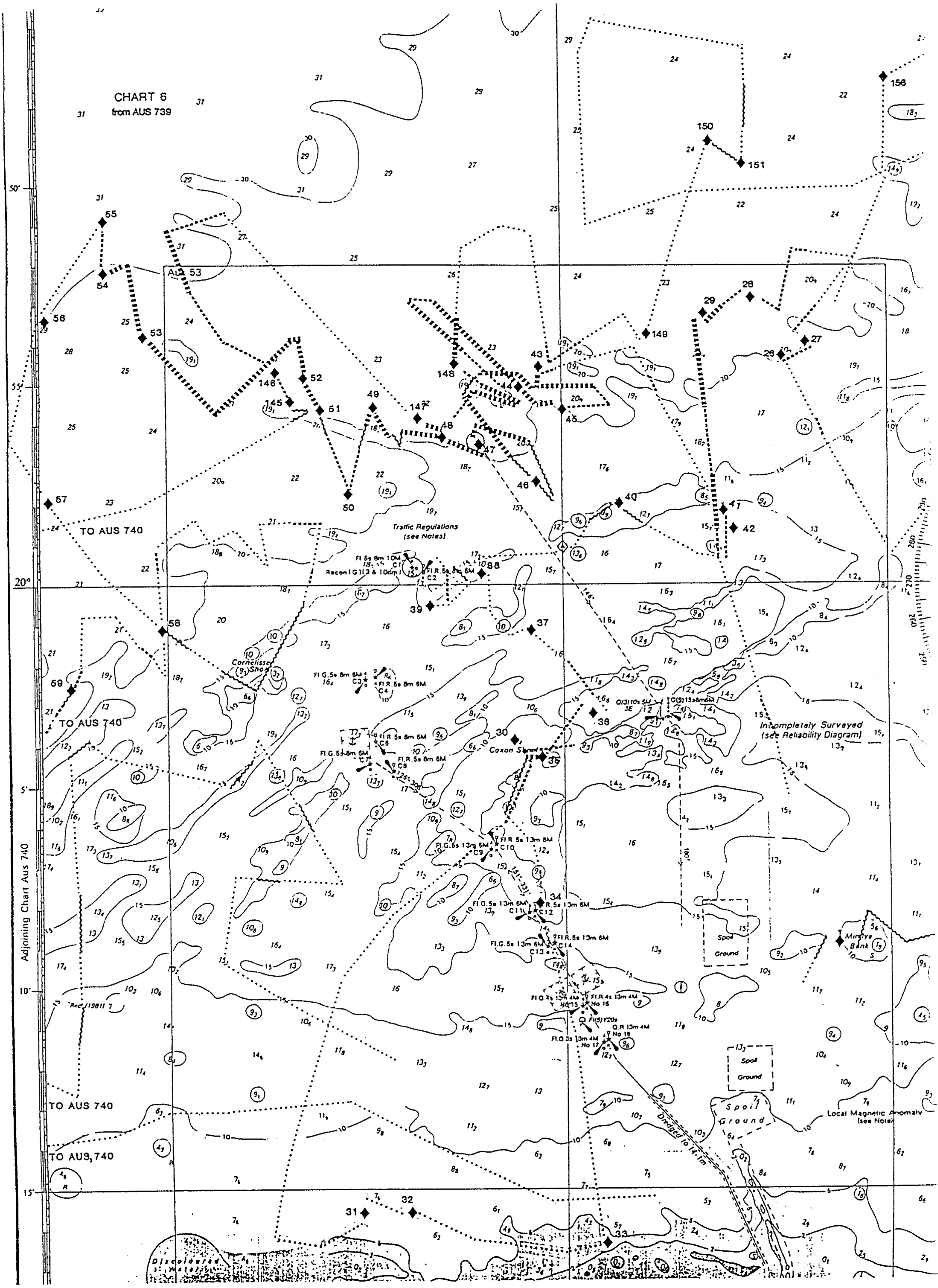


CHART 6
from AUS 739
AUS 53
TO AUS 740
TO AUS 740
TO AUS 740
TO AUS 740
Adjoining Chart Aus 740
Traffic Regulations
(see Notes)
Cornelisse Shoal
Coxon Shoal
Incompletely Surveyed
(see Reliability Diagram)
Spoil Ground
Spoil Ground
Spoil Ground
Local Magnetic Anomaly
(see Note)
Discoloured Water

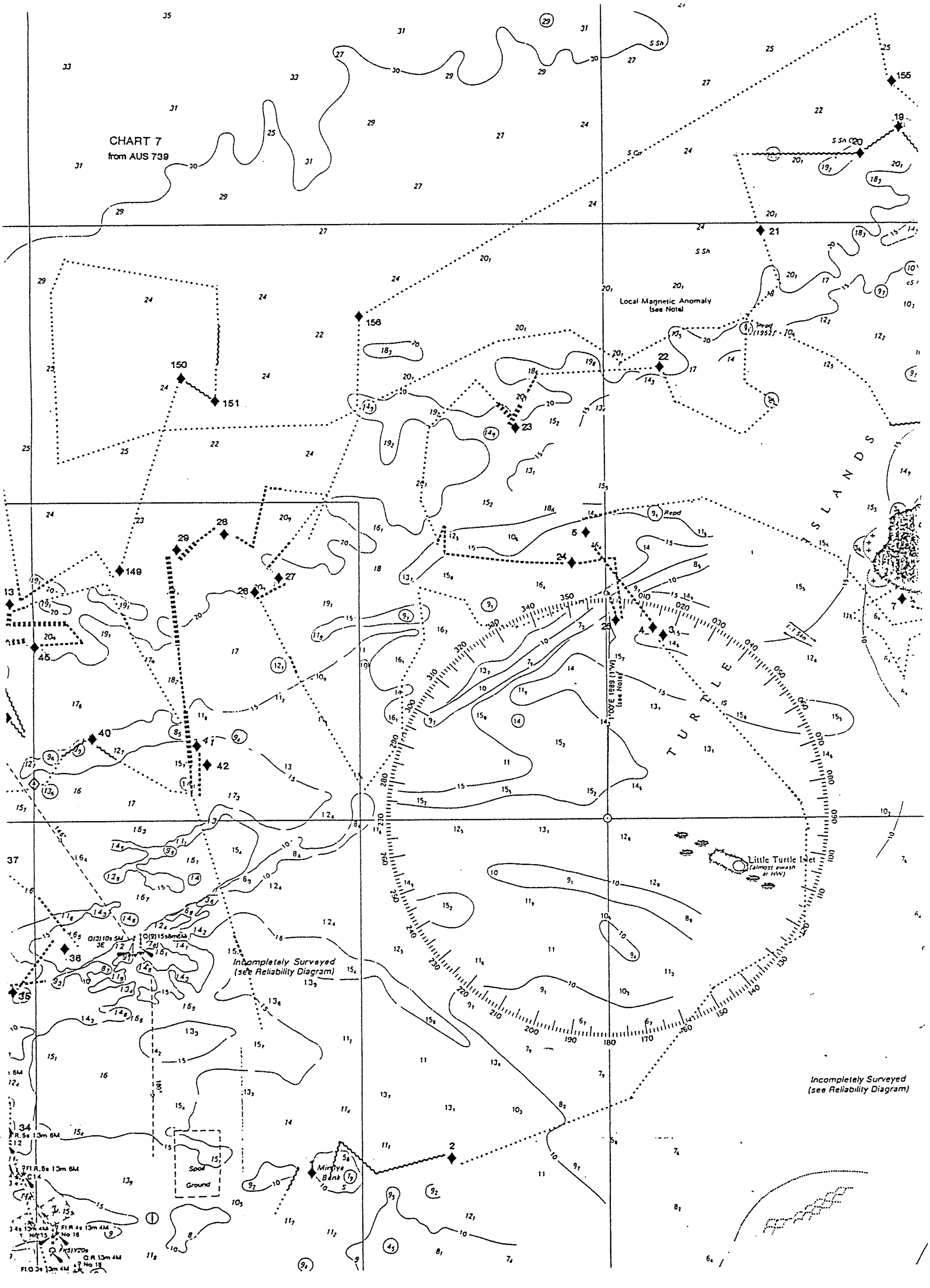


CHART 7
from AUS 739
Local Magnetic Anomaly
(see Note)
TURTLE
ISLANDS
Little Turtle Islet
(almost awash at HW)
Incompletely Surveyed
(see Reliability Diagram)
Incompletely Surveyed
(see Reliability Diagram)
Spoil Ground

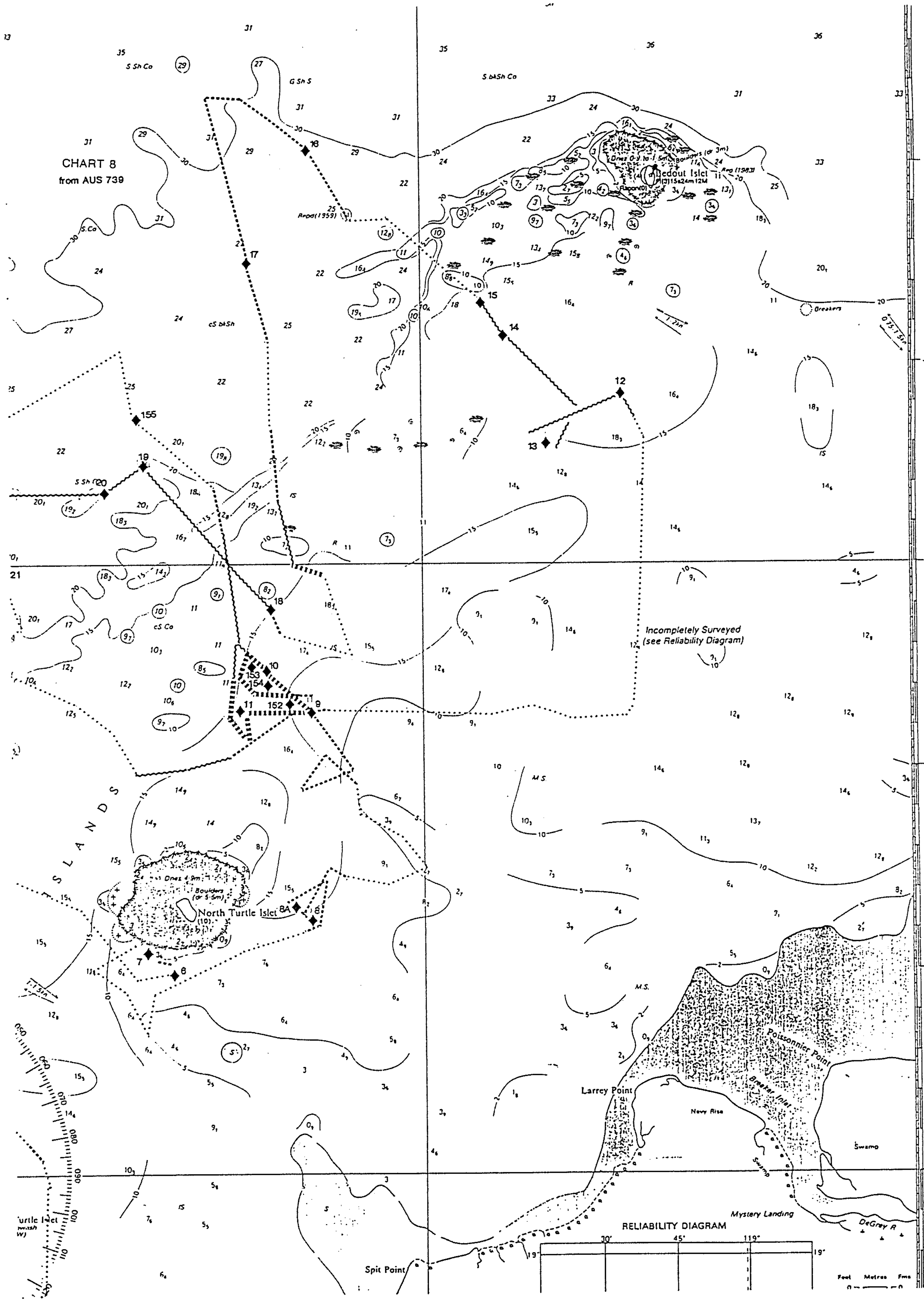


CHART 8
from AUS 739
Bedout Islet
Incompletely Surveyed
(see Reliability Diagram)
ISLANDS
North Turtle Islet
Larrey Point
Poissonnier Point
Breaker Inlet
Navy Rise
Swamp
Mystery Landing
DeGrey R
Spit Point
RELIABILITY DIAGRAM

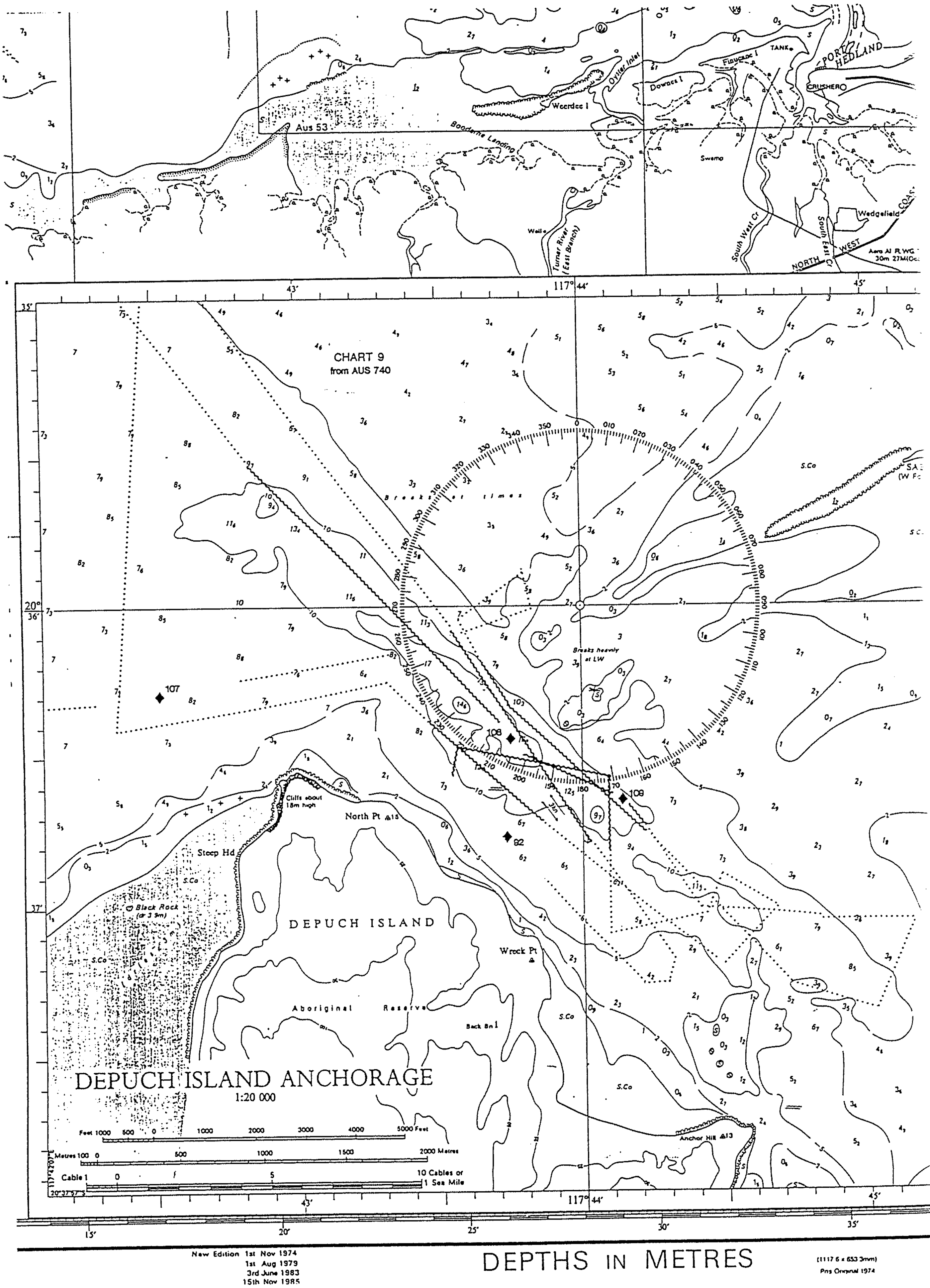


CHART 9
from AUS 740
Aus 53
Weerdee I
Oyster Inlet
Boodarrie Landing
Dowacs I
Finucane I
TANK
PORT HEDLAND
CRUSHERO
Swamp
Wedgefield
South West Cr
South East Cr
NORTH WEST COAST
Turner River (East Branch)
Wells
Breaks at times
Breaks heavily at LW
Cliffs about 18m high
North Pt
Steep Hd
Black Rock (dr 3 9m)
DEPUCH ISLAND
Wreck Pt
Aboriginal Reserve
Anchor Hill
DEPUCH ISLAND ANCHORAGE
1:20 000
Feet 1000 500 0 1000 2000 3000 4000 5000 Feet
Metres 100 0 500 1000 1500 2000 Metres
Cable 1 0 5 10 Cables or 1 Sea Mile
New Edition 1st Nov 1974
1st Aug 1979
3rd June 1983
15th Nov 1985
DEPTHS IN METRES